Historical and spatial trends in selected aspects of the finfish aquaculture industry in southwestern New Brunswick, Bay of Fundy, 1978-2012

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TABLE OF CONTENTS

Abstract iv
Résumé iv
Introduction 1
Methods and data sources 2
Salmon aquaculture production (quantity and value) 6
Non-salmonid finfish aquaculture production 7
Aquaculture Bay Management Areas 7
Number of farms and farm ownership 8
Farm locations 9
Production of salmon smolts for aquaculture in New Brunswick 9
Stocking rates 11
Growout times and harvest weights 12
Trends in selected farm characteristics 12
Fisheries landings in the Bay of Fundy (New Brunswick portion) 18
Acknowledgements 19
References 19
Tables 26
Figures 28

ABSTRACT

Chang, B.D. and Page, F.H. 2014. Historical and spatial trends in selected aspects of the finfish aquaculture industry in southwestern New Brunswick, Bay of Fundy, 1978-2012. Can. Tech. Rep. Fish. Aquat. Sci. 3112: iv + 70 p.

The finfish aquaculture industry in southwestern New Brunswick (SWNB), in the Bay of Fundy, began in 1978. In 2012 there were 92 marine finfish leases, but only half were active. Atlantic salmon *Salmo salar* has been the dominant species since the beginning of the industry, and it is currently the only finfish species commercially grown in marine cages in SWNB. Farmed salmon production in SWNB in 2012 was estimated to be 30 217 t, with a value of C$185 million. Trends over time in various aspects of the industry are presented, including: total production and value, the number and locations of marine growout farms, the number of commercial salmon hatcheries, stocking rates, cage types, lease areas, water depths at farms, distances between farms, predicted current speeds at farms, and seafloor sediment types at farms. Commercial fisheries landings data for the New Brunswick portion of the Bay of Fundy during the period when salmon farming developed are also presented.

RÉSUMÉ

Chang, B.D. and Page, F.H. 2014. Historical and spatial trends in selected aspects of the finfish aquaculture industry in southwestern New Brunswick, Bay of Fundy, 1978-2012. Can. Tech. Rep. Fish. Aquat. Sci. 3112: iv + 70 p.

La pisciculture dans la baie de Fundy, dans le Sud-Ouest du Nouveau-Brunswick, a débuté en 1978. En 2012, on comptait 92 baux d'exploitation aquacole en mer, mais seule la moitié d'entre eux étaient actifs. Le saumon de l'Atlantique *Salmo salar* est l'espèce dominante depuis le début de l'industrie, et c'est actuellement la seule espèce de poisson élevée à des fins commerciales dans des cages marines dans le Sud-Ouest du Nouveau-Brunswick. La production de saumons d'élevage dans le Sud-Ouest du Nouveau-Brunswick a été estimée en 2012 à 30 217 tonnes, pour une valeur de 185 millions de dollars canadiens. Les tendances au fil du temps de divers aspects de l'industrie sont présentées, notamment : la production et la valeur totales, le nombre d'exploitations de grossissement en milieu marin et leur emplacement, le nombre d'écloseries commerciales de saumon, les taux de mise en charge, les types de cage, les zones de concession, la profondeur de l'eau dans les exploitations, les distances entre exploitations, les vitesses de courant prévues dans les exploitations et les types de sédiments du fond marin dans des exploitations. Les données sur les débarquements de la pêche commerciale pour la partie du Nouveau-Brunswick de la baie de Fundy au cours de la période pendant laquelle la salmoniculture s'est développée sont également présentées.

INTRODUCTION

The first marine salmon farm in southwestern New Brunswick (SWNB), in the Bay of Fundy, began operating in 1978. This farm had its first harvest, 6 t, in 1979. In 2012 there were 92 marine finfish leases in SWNB, in an area approximately 60 × 60 km (Fig. 1); however, only half of these leases were active. Salmon aquaculture production in SWNB in 2012 was estimated to be 30 217 t, with a value of C$185 million (Statistics Canada 2013). Atlantic salmon *Salmo salar* has been the dominant aquaculture species in SWNB since the beginning of the industry, and it was the only commercial finfish species grown at marine farms in SWNB in 2012.

SWNB is the most important salmonid mariculture area in Atlantic Canada. Although production has fallen in recent years, SWNB still produced slightly more than half of the total salmonid mariculture production in Atlantic Canada in 2012 (Statistics Canada 2013). Because of winter temperature and ice conditions, the only areas in Atlantic Canada that are considered to be suitable for year-round marine salmon culture are SWNB, southwestern Nova Scotia, Bras d'Or Lake (Cape Breton Island), and southern Newfoundland (Anderson & Associates 1980; Cook et al. 1987; Saunders 1995). The minimum lethal temperature for Atlantic salmon is -0.7 to -0.8°C, while temperatures <1°C are unfavorable for feeding and growth (Saunders et al. 1975). In SWNB, winter temperatures generally remain above the lethal lower limit, but temperatures <1°C occur in most winters at some locations (see data reported in Robinson et al. 1996 and Chang et al. 2011). In some winters, salmon mortalities attributed to cold temperature have occurred in SWNB, usually at shallow, poorly-flushed farms (Page & Robinson 1992; Saunders 1995). Temperatures >16°C are also considered to be unsuitable for marine culture of Atlantic salmon (Saunders 1995), but such temperatures are rare in SWNB (see Robinson et al. 1996 and Chang et al. 2011). However, during the last few years, salmon farms in SWNB have reported above normal temperatures (ACFFA 2013); if temperatures continue to rise, there could be an increased risk of unsuitably high summer temperatures, while the risk of lethal low winter temperatures may decrease.

A recent publication (Chang et al. 2014) described the historical development of the SWNB salmon farming industry. The present report provides additional information on historical trends in various aspects of the salmon farming industry in SWNB up to 2012, including supplementary data used in the preparation of the Chang et al. (2014) publication. The data presented include historical trends in the production of farmed salmon and other finfish species, the number and locations of salmon hatcheries, the number and locations of marine growout farms, stocking rates, cage types, lease areas, site depths, predicted water current speeds at farms, distances of farms from shore, distances between neighboring farms, and seafloor sediment types at farms. Also presented are data on fisheries landings in the New Brunswick portion of the Bay of Fundy during the period when the SWNB salmon aquaculture industry developed.

METHODS AND DATA SOURCES

Historical information on the salmon farming industry in SWNB was obtained from several earlier reports: FGA & WGA (1988); Cook (1988, 1990); Aiken (1989); Saunders (1995); Chang (1998); Doane Raymond & ARA Consulting Group (1998); Stewart (2001); Anderson (2007); and CMC & Ridler (2009). Much of the information used in the preparation of this report was obtained from the New Brunswick Department of Agriculture, Aquaculture & Fisheries (NBDAAF, St. George, NB) and its predecessors, the New Brunswick Department of Agriculture & Aquaculture (NBDAA) from 2006-2010, and the New Brunswick Department of Fisheries & Aquaculture (NBDFA) from 1988-2006; and from Fisheries and Oceans Canada (DFO, St. George, NB and Dartmouth, NS).

Maps were drawn using MapInfo Professional (v. 8.0). The coastline of SWNB (at high water) was downloaded from the Natural Resources Canada CanVec database (available at the GeoGratis website: www.geogratis.gc.ca).

Salmon aquaculture production (quantity and value)

Production data exclude hatcheries and processing. Values are in Canadian dollars (C$); historical values are not adjusted for inflation. The following data sources were used:

- DFO (2014a): data by Canadian province, 1986-2012
- Statistics Canada (2013): data by Canadian province, 2008-2012
- NBDFA (1998): data for New Brunswick, 1978-1997
- Newfoundland and Labrador Department of Fisheries & Aquaculture (NLDFA 2013): data for Newfoundland and Labrador, 2005-2012
- Maine Department of Marine Resources (MDMR 2014): data for Maine, 1988-2010
- Food and Agriculture Organization of the United Nations (FAO 2014): global data, 1980-2012.

Canadian dollar exchange rates were obtained from the Bank of Canada website (www.bankofcanada.ca/rates/exchange/); the website currently shows rates since 1997.

Non-salmonid finfish aquaculture production

Data on the number and locations of farms growing non-salmonid species each year were obtained from NBDAAF (St. George, NB). Production data for non-salmonid finfish species in SWNB were only available for 2006-2010 (NBDAAF 2008-2011).

Aquaculture Bay Management Areas (ABMAs)

The ABMA framework which was implemented in 2006 is defined in NBDAA (2007). ABMA 4 was incorporated into ABMA 1 in 2010. For the analyses in this report, ABMA 1 was sub-divided into 1-north (northern Passamaquoddy Bay) and 1-south (Deer and Campobello Islands).

Number of farms, farm ownership, farm locations, and farm ages

The locations of current farms were obtained from NBDAAF (2014). Historical data on the number of farms, farm ownership, and farm locations were obtained from NBDAAF (St. George, NB). Farms were considered to be active if they operated for ≥1 month in a given year; when information was not available for a farm in a given year, it was assumed that the farm was active. Farms were considered to have started in the year when fish were first stocked (in some cases, this was a year or more after the farm had been approved). Not included were some farms that started in the 1980s, but failed during their first year of operations; these farms were considered to have started if and when successful operations began in subsequent years. Also excluded were some farms that were approved, but never stocked. Companies with different names, but the same ownership or management, were combined. Farm age was defined as the difference in years between 2012 and the year when the farm started operating, regardless of whether the farm had operated during all of the intervening years.

Data on the number of finfish leases and locations in Maine were obtained from the Maine Department of Marine Resources (West Boothbay Harbor, ME): MDMR (1990, 2000, 2014, and unpublished data).

Number of salmon hatcheries and total number of smolts stocked

Estimates of the number of salmon hatcheries in New Brunswick and the total number of salmon smolts stocked at SWNB farms were found in: Scarratt (1987); Cook (1988); FGA & WGA (1988); Deloitte & Touche (1990); Price Waterhouse Management Consultants (1991); Anderson (2007); CMC & Ridler (2009); and data obtained from NBDAAF (St. George, NB) and the New Brunswick Department of Environment & Local Government (NBDELG, Fredericton, NB).

Stocking rates per farm

Estimates of actual numbers of salmon smolts stocked were available for all farms during 1986-1989 and 2005-2012, and for many farms during 1998-2004 (FGA & WGA 1988; NBDAAF, St. George, NB; DFO, St. George, NB and Dartmouth, NS). The stocking rates shown are for transfers of smolts from hatcheries to marine cage sites; transfers of salmon between marine cage sites were excluded. Estimates of actual numbers stocked were unavailable for most farms during 1990-1997 and for many farms during 1998-2004; in these cases, stocking rates were estimated using the allowable production levels (APLs), which were designated by NBDFA during 1989-2005. The APL was the maximum number of fish allowed on each farm at any time. When using APLs to estimate stocking rates, farms which were known to have not stocked in a given year were excluded, and it was assumed that multi-year-class farms stocked half of the APL in each year and single-year-class farms stocked the entire APL every other year (during 1989-2005).

Growout times and harvest weights

For the 1986 and 1987 year-classes, estimated average growout times, harvest weights (per fish), and harvest biomasses (per farm) were obtained from a survey of all SWNB salmon farms that stocked in those years (FGA & WGA 1988). For the 1995 year-class, data on growout times and harvest weights were obtained from a study at 20 farms (data from 3 cages per farm) that stocked that year-class (Peterson et al. 2001); the estimated average harvest biomass per farm was calculated using the estimated average stocking rate per farm for the 1995 year-class (based on APLs). Other estimates of average growout times and harvest weights were reported in Doane Raymond & ARA (1998), Stewart (2001), and CMC & Ridler (2009).

Cage types

Information on cage types was obtained from several sources: FGA & WGA (1988); Anderson (2007); aerial images from Google Earth (www.google.com/earth/index.html); aerial images from GeoNB Map Viewer (geonb.snb.ca/geonb/); aerial photographs taken in 1989 by NBDELG (Fredericton, NB); aerial photographs taken by DFO St. Andrews Biological Station staff in various years; and NBDAAF (St. George, NB).

Lease boundaries and areas

Current lease boundaries and areas were obtained from NBDAAF (2014) and from survey maps provided by NBDAAF (St. George, NB). Historical data were obtained from NBDAAF (St. George, NB) and the New Brunswick Department of Natural Resources (Fredericton, NB). Lease boundaries exclude intertidal foreshore areas.

Water depths

Bathymetry data (depths below lowest normal tide) for SWNB were obtained from the Canadian Hydrographic Service (Dartmouth, NS). The depth value for each farm was calculated as the arithmetic mean of all subtidal depth soundings within the lease boundary. Note that the average depth within the lease may not be representative of the depth where cages are located; for example, at shallow farms, cages may be located only in deeper areas of the lease.

Current speeds

Current meter records of $\geq$30 d duration were not available for most farm leases. To estimate current speeds at all farms, we used a three-dimensional, finite element particle tracking model (Greenberg et al. 2005) that was customized for a study that examined the potential for disease spread among salmon farms in the SWNB area (Chang et al. 2005). The model was run using boundary forcing by the principal lunar tide (M2) alone. The model produced estimates of the initial speeds of 36 particles which were released from locations evenly spaced within a 200 $\times$ 200 m grid located near the centre of each farm lease. The model particles were released and maintained at a depth of 1 m below the water surface. Particle releases were repeated twelve

times, at hourly intervals, in order to represent releases throughout one tidal cycle (12.4 h), for a total of 432 particles released from each farm (except slightly fewer at some small farms, where the lease area was too small to contain a 200 × 200 m grid). Particle positions were calculated at 20 min intervals. The predicted mean surface current speed at a farm was calculated as the arithmetic mean of the speeds of all 432 model particles released from that farm during the first 20 min interval after release.

Distances between farms and the shore and between neighboring farms

Distances of farms from the shore were calculated using the MapInfo Distance Calculator tool to draw the shortest line from the approximate farm centre to the coastline (the high water line, excluding small islands <10 ha in area). Distances between nearest neighboring farms were calculated using the MapInfo Distance Calculator tool to draw the shortest line between each lease boundary and its nearest neighbor. If the line went over land, it was manually adjusted to go through water (around the high water coastline) to the nearest lease.

Sediment types under farms

Complete grain size analyses (% silt-clay, sand, and gravel/rock) of seafloor sediments were not available for most farm sites in SWNB. However, data on the % silt-clay (the % of particles <0.063 mm, based on dry weight, following wet sieving) were available for most sites (from NBDAAF, St. George, NB). Using these data, farms were classed as having >66%, 33-66%, or <33% silt-clay sediments. Quantitative % silt-clay data were available for 77 of the 92 finfish leases in 2012. Quantitative pre-site baseline data were used to classify farms, where available: at 24 farms, including all new farms since 2001 and a few older farms. Quantitative data were also collected from 53 other farms after they had started operating; where such data were available from more than one year, average values were used to classify farms. Qualitative descriptive data were used to classify 15 farms for which quantitative data were not available: pre-site baseline descriptive data were available for 13 new farms during 1994-1998; descriptions of sediment conditions included in environmental monitoring reports were the only data available for 2 other farms. For these 15 farms, sediments described as predominantly fine, mud, or silt-clay were classed as >66% silt-clay; sediments described as predominantly coarse, cobble, gravel, or rock were classed as <33% silt-clay; and sediments described as mixed (fine and coarser) were classed as 33-66% silt-clay.

Fisheries statistics

Data on fisheries landings and value for the New Brunswick portion of the Bay of Fundy (NB Fundy) for 1990-2012 were obtained from DFO (2014b); earlier data were obtained from DFO's Policy & Economics Branch (Dartmouth, NS). Additional data for the herring fishery were found in DFO (2013a) and Power et al. (2013). Data for the wild salmon fishery were obtained from May & Lear (1971); Cutting (1984); Smith (1981); Swetnam & O'Neil (1984); O'Neil et al. (1985, 1986, 1987, 1989, 1991); and DFO (2013b).

SALMON AQUACULTURE PRODUCTION (QUANTITY AND VALUE)

The first finfish farm in SWNB grew Atlantic salmon and also conducted comparative trials with steelhead (rainbow trout) *Oncorhynchus mykiss* and pink salmon *Oncorhynchus gorbuscha* in 1978-1979 (Sutterlin et al. 1981). Atlantic salmon has been the main species grown since then, and in 2012 was the only commercial finfish species grown at marine farms in SWNB. However, most of the new farms that started in 1984 and 1985 began with steelhead, due to a shortage of salmon smolts. Since then, a few farms have grown steelhead, as well as another salmonid species, Arctic char *Salvelinus alpinus*, in some years, but production quantities for these species have never been large (production data for these species were not available; quantities for these species were probably included within salmon production figures).

Historical trends in the production quantity and value of the SWNB salmon aquaculture industry (excluding hatcheries and processing) are shown in Fig. 2. Initially, industry growth was slow, primarily due to a lack of financing and a shortage of smolts. Starting in 1984, government financial assistance was provided and smolt production by commercial hatcheries increased, leading to rapid growth in the industry. Production fell in 1998 due to an outbreak of infectious salmon anemia (ISA), but quickly recovered, and grew again until a re-occurrence of ISA, and the implementation of management actions to address this issue, which led to a decline in production after 2006. Further information on historical production trends can be found in Chang et al. (2014).

The price of salmon (per kg, excluding processing) peaked in 1987 at C$16.60 per kg, but then fell to as low as C$5.00 per kg in 2002 and 2004 as global production increased (Fig. 3). In 2012 the average price was C$6.10 per kg. Prior to 1987, just 5-10% of the SWNB farmed salmon production was exported to the US. This figure increased to 40% in 1987-1988 (FGA & WGA 1988), ~75% in 1996 (Doane Raymond & ARA Consulting Group 1998), and ~60% since 2000 (Stewart 2001; CMC & Ridler 2009). Because the majority of the farmed salmon production in SWNB is exported to the USA, the value of the Canadian dollar (relative to the US dollar) has a large impact on the industry: when the value of the Canadian dollar is low, the price of the product in the USA market decreases, thus making the product more attractive to USA buyers. The Canadian dollar was as low as US$0.64 in 2002, but rose to near par with the US dollar during 2010-2012 (Fig. 3).

Trends in salmonid mariculture production (including Atlantic salmon, Pacific salmon, and marine trout) in Canada (by province) and in Maine are shown in Fig. 4. From the late 1980s to 2005, SWNB production represented ~30% of Canadian salmonid mariculture production and ≥75% of production in Atlantic Canada (Fig. 5). Since that time, the SWNB share has fallen, as a result of lower production in SWNB and increased production in southern Newfoundland. In 2012 SWNB salmonid mariculture production represented 23% of Canadian production and 52% of production in Atlantic Canada. As a percentage of global salmonid mariculture production, SWNB production reached 2.8% in 1992 and 2.7% in 2003, but has fallen to ~1% in recent years

(Fig. 6). The decrease is a result of lower production in SWNB and increased production elsewhere, especially in Norway and Chile.

NON-SALMONID FINFISH AQUACULTURE PRODUCTION

The main non-salmonid finfish species that have been grown at marine cage sites in SWNB are haddock *Melanogrammus aeglefinus*, Atlantic halibut *Hippoglossus hippoglossus*, and Atlantic cod *Gadus morhua*. These species were grown alongside salmon at some farms (in separate cages), while a few farms grew only non-salmonid species. The first non-salmonid marine trials were at a farm at Campobello Island that started growing haddock in late 1991 (but most of the cages at this farm continued growing salmon). The Canada–New Brunswick–Nova Scotia New Finfish Aquaculture Species Development Program funded research on new aquaculture species during 1995-2000, with the aim of promoting diversification in the SWNB aquaculture industry (Chang 2001). The number of marine farms growing non-salmonid species peaked in 2003, when there were 10 sites, of which 4 grew only non-salmonids (Fig. 7). However, mariculture of non-salmonid species has so far not been commercially successful in SWNB; in 2012 there were no marine sites growing non-salmonid finfish aquaculture species. However, there were two companies growing shortnose sturgeon *Acipenser brevirostrum* in land-based facilities in SWNB in 2012. The production of non-salmonid finfish species (including sturgeon) in SWNB has not exceeded 125 t per year (Fig. 7), which is <1% of farmed salmon production. There were also trials at one marine site in 2011-2012 growing cunners *Tautogolabrus adspersus* in cages, together with salmon; these trials were examining the feasibility of using cunners to control sea lice on farmed salmon. Integrated multi-trophic aquaculture (IMTA), growing mussels *Mytilus edulis* and kelp (various species) alongside finfish, was first tested in SWNB at one farm in 2001 (Chopin & Robinson 2004); in 2012 there were 8 farms practising IMTA in SWNB.

AQUACULTURE BAY MANAGEMENT AREAS

Fish farms in SWNB are managed within a framework of Aquaculture Bay Management Areas (ABMAs; Fig. 1). ABMAs were implemented primarily for fish health management, especially outbreaks of ISA. For details on the evolution of ABMAs in SWNB, see Chang et al. (2014). The current ABMA framework was implemented starting in 2006 and is based on single-year-class farming with a 3-year crop rotation system and mandatory fallowing of farms and ABMAs between year-classes. The ABMA designations are as follows (NBDAA 2007):

- ABMA 1 (Passamaquoddy Bay, Deer Island, and most of Campobello Island): stocking in 2006, 2009, and 2012.
- ABMA 2a (Letang area, including Lime Kiln Bay, Bliss Harbour, and Back Bay): stocking in 2007, 2010, and 2013.
- ABMA 2b (eastern Grand Manan Island): stocking in the same years as ABMA 2a.
- ABMA 3a (mainland coast east of ABMA 2a, including Beaver Harbour and Maces Bay): stocking in 2008, 2011, and 2014.

- ABMA 3b (southern Grand Manan Island): stocking in the same years as ABMA 3a.
- ABMA 4 (Harbour de Loutre, Campobello Island): stocking years were not designated for the 3 farms in this small ABMA; in 2010, ABMA 4 was incorporated into ABMA 1.
- ABMA 5 (Dark Harbour, Grand Manan Island): stocking years were not designated in this small, isolated ABMA with only one farm; there has been no lease in this ABMA since 2008.
- ABMA 6 (Letete Passage): this area was designated for non-salmonid species only; however, 2 of the 3 farms in this ABMA were inactive during 2006-2012, and the third grew cod, but has been inactive since 2011.

NUMBER OF FARMS AND FARM OWNERSHIP

Trends in the numbers of finfish leases, active farms, new farms, and farm ownership are shown in Fig. 8. Since 2002, there have been few new farms, largely because there are few suitable nearshore locations remaining in SWNB.

In the early years, all leases were usually active continuously every year. Since the early 2000s the number of active leases has declined due to various factors, including the implementation of single-year-class farming and ABMAs, as well as fish health and economic factors (Chang et al. 2014). As noted above, the current ABMA framework, which was implemented in 2006, is based on single-year-class farming on a 3-yr stocking cycle, and includes mandatory fallowing between consecutive year-classes at each farm. The fallow period at each farm should be at least 4 months; however, fallow periods since 2006 have usually been longer, averaging ~11 months.

There has been consolidation in farm ownership over time. In 1984 the 6 active farming companies each operated only one farm. In 1989 there were 43 active farms, but most companies still operated only one farm: there were 37 companies, of which one had 3 farms, 4 companies had 2 farms, and the rest had only 1 farm each; however, it was estimated that 30-40% of the total SWNB production in 1989 came from just 3 companies (Price Waterhouse Management Consultants 1991). Ten years later, in 1999, there were 84 active farms, operated by 38 companies; the 2 largest companies each operated 8 farms, together representing about one-quarter of the total SWNB salmon production (based on APLs). The implementation of single-year-class farming on a 2-year rotation (in 2000) meant that companies had to operate at least 2 farms (in different ABMAs) to be able to produce market fish every year. In 2004 there were 81 active farms; the 2 largest companies each operated 13 farms, together representing about one-third of the total SWNB salmon production (based on APLs). The implementation of single-year-class farming on a 3-year rotation in 2006 meant that companies had to operate at least 3 farms (in different ABMAs) to be able to produce market fish each year. As a result of this, together with economic factors, the industry is now controlled by just a few companies: the 45 active salmon farms in 2012 were operated by just five companies, with one company operating 60% of the active farms, representing about two-thirds of the total SWNB production.

FARM LOCATIONS

Fig. 9 is a series of maps showing the locations of finfish leases in SWNB from 1984-2012; these maps also show which farms were actively growing salmon and other species. The first salmon farm was started in 1978 at Lords Cove, on the east coast of Deer Island, and the second farm started in 1980 in Dark Harbour, on the west coast of Grand Manan Island. Early industry growth was concentrated in the Letang area of the mainland coast and around Deer and Campobello Islands. The industry later grew along the southern and eastern shores of Grand Manan Island and in northern Passamaquoddy Bay. In the late 1990s and early 2000s, the industry spread eastward along the mainland coast into the Maces Bay area and beyond.

Trends in the numbers of finfish leases and active salmon farms within ABMAs are shown in Fig. 10. All farms in northern Passamaquoddy Bay (ABMA 1-north) were inactive in 2012, as were many farms around Deer Island (ABMA 1-south) and in the Letang area (ABMA 2a).

PRODUCTION OF SALMON SMOLTS FOR AQUACULTURE IN NEW BRUNSWICK

In salmon aquaculture, smolts are produced in freshwater hatcheries, and then transferred to marine cage sites for growout to market size. In 1990, 40-60% of smolts used in SWNB aquaculture were S1s (age 1+ yr), with the rest being S2s (age 2+ yr), while in Norway, most aquaculture smolts were S1s (Deloitte & Touche 1990). The higher proportion of S2 smolts in SWNB at that time meant higher smolt production costs. Research on factors involved in smoltification led to improvements in hatchery techniques, which shortened the time required to produce smolts (Saunders 1995). In 1998 it was reported that most aquaculture smolts in SWNB were S1s, with <5% S2s, and ~10% S0 fall smolts (age <1 yr) (S.M. McGeachy, NBDFA, St. George, NB, pers. comm., reported in Chang 1998). Currently, most smolts in SWNB aquaculture are S1s, with ~15% S0s; the average smolt size is ~85 g (range: 60-125 g).

Initially, all smolts in SWNB were stocked at marine farms in the spring (April-June). Since the 1990s, the smolt transfer season has been extended, so smolts can now be stocked from April-December. Currently ~70% of smolts are stocked in the spring.

In the earliest years of the industry, the smolts stocked at SWNB farms were surplus smolts produced by DFO salmon enhancement facilities on the St. John River (Mactaquac and Saint John hatcheries), as well as some smolts produced at the St. Andrews Biological Station (Anderson 2007). The number of smolts supplied by DFO hatcheries for stocking at SWNB farms grew during the 1980s (Scarratt 1987; Farmer 1991), peaking at ~200 000 in 1988 (Cook 1988). However, the growth in production by commercial hatcheries meant that by 1988 the DFO smolts represented only ~15% of the total number stocked at SWNB farms. DFO hatcheries continued supplying some smolts to the industry, but in much smaller numbers, into the 1990s, primarily for broodstock development and research (Farmer 1991).

The first commercial salmon hatcheries in New Brunswick began operating in 1982 (FGA & WGA 1988). The trend over time in the number of commercial hatcheries in New Brunswick producing Atlantic salmon smolts for aquaculture is shown in Fig. 11 & 12. The number of commercial hatcheries in New Brunswick peaked at 26 in 2003-2004; the number has fallen since then, due to lower demand for smolts (fewer farms being stocked) and consolidation of ownership within the SWNB aquaculture industry (see below), which led to the closure of many smaller, independent hatcheries.

Most of the Atlantic salmon smolts produced by commercial hatcheries in New Brunswick were stocked at marine growout sites in SWNB. However, in some years, some smolts produced at New Brunswick hatcheries have been stocked at farms in Nova Scotia, Newfoundland, and Maine, and some smolts produced in hatcheries outside of New Brunswick (in Nova Scotia, Prince Edward Island, and Maine) have been stocked at farms in SWNB.

Initially, salmon broodstock for commercial hatcheries were held at a few marine growout sites, in separate cages from production fish. During 2000-2002, all broodstock were moved to land-based freshwater facilities, as part of the strategy to manage ISA.

In February 1994, NBDFA introduced a policy on the allocation of parr/smolt acclimation sites at brackish water sites in SWNB. At the time, the use of such sites was thought to be a cost effective method for increasing smolt production. The concept was to place salmon parr in net cages at brackish water sites during the spring; these fish would then be transferred (as smolts) to marine growout sites in the fall. There were 5 parr/smolt acclimation sites that operated during 1994-1998 (Fig. 13). Two were previously approved sites. One site in Kennebecasis Bay (near Saint John) had been growing smolts in cages since 1985; although year-round culture was allowed at this site, the maximum permitted stocking density of 2.5 kg m^{-3} meant that smolts could not be grown out to market size. A site in the Magaguadavic River estuary had been operating seasonally since 1988; this site was approved for year-round culture of salmon, trout, and Arctic char, but found to be unsuitable for year-round use because of low winter water temperatures and ice. There were three new parr/smolt acclimation sites: two in the Magaguadavic River estuary started operations in 1994 and one in Kennebecasis Bay started in 1996. The maximum stocking density at the three new sites was limited to 2 kg m^{-3} (compared to 18 kg m^{-3} at marine growout sites) and fish were allowed on site only during April-December (i.e. growout to market size was not allowed).

As a result of the ISA outbreak, the policy regarding parr/smolt acclimation sites was changed. Transferring of fish among sites was considered to be a risk factor for the spread of ISA and, consequently, this practise was prohibited in early 1998. As a result, these sites could no longer be used for parr/smolt acclimation. Two of the sites (the newer Kennebecasis Bay site and one of the Magaguadavic estuary sites) ceased operating after the policy change. The other two Magaguadavic estuary sites grew trout for one or two years before ceasing operations, and the

older site in Kennebecasis Bay grew Arctic char until ceasing operations in 2004 (Anderson 2007).

STOCKING RATES

The estimated total number of smolts stocked per year in SWNB increased up to 2002-2003, but has decreased since then (Fig. 14). The decrease in recent years has been due to fish health issues (primarily ISA and sea lice) and the implementation of fish health management practices (including ABMAs and fallowing), as well as economic factors. However, the average number of smolts per stocked farm has continued to increase (Fig. 14), as the number of farms stocked per year has decreased (see below).

New farms that were provided with government financial assistance during 1984-1986 started with just one or two small cages and 2 500 – 5 000 salmon smolts (or steelhead) in their first year, plus an additional 4 cages and 10 000 smolts in their second year (FGA & WGA 1988). It was understood that farm sizes would need to increase over time. Henderson (1985) estimated that an economically viable farm at that time would need to have 24 cages, holding 60 000 fish (30 000 in each of two year-classes).

Initially, all salmon farms in SWNB were multi-year-class operations, holding 2 or more year-classes at the same time. In 1988 only 2 of 39 active salmon farms were single-year-class operations, and in 1992 only 4 of 53 active farms were single-year-class operations. At the time of the initial ISA outbreak in 1996, there were still very few single-year-class farms. To manage the outbreak of ISA, all farms in Lime Kiln Bay, Bliss Harbour, and Back Bay (current ABMA 2a), as well as Seal Cove (part of current ABMA 3b), were required to fallow from mid-1998 (all except Back Bay) or early 1999 (Back Bay), prior to restocking as single-year-class operations in 1999 (these farms were not allowed to stock smolts in 1998). Some farms in other areas also became single-year-class operations around this time. In early 2000, there were only 11 multi-year-class farms (of a total 84 active salmon farms). The site allocation policy implemented in 2000 (NBDAFA 2000a & 2000b) introduced the first Aquaculture Bay Management Area (ABMA) framework, consisting of 21 ABMAs (revised to 22 in 2001). This policy also included the requirement that all salmon farms become single-year-class operations on a two-year production cycle. By the fall of 2002 all SWNB salmon farms had become single-year-class operations (McGeachy & Moore 2003). However, this policy allowed farms to holdover up to 20% of the market fish on site when the next year-class of smolts was introduced (although the market fish could not be held beyond September), so some overlap between consecutive year-classes was permitted. A new ABMA framework, with far fewer (but larger) ABMAs, was introduced in 2006 (see above), primarily because of continuing problems with ISA, as well as market challenges. The new ABMA framework supported true single-year-class production on a three-year cycle, with mandatory fallowing between successive year-classes.

The switch to single-year-class farming was the major reason for the decrease in the number of farms that stocked each year after 1997, as well as the concurrent increase in the average number of smolts stocked per farm (Fig. 15). A multi-year-class farm, operating on a 2-year rotation system, would usually stock about half of its APL every year (so the total number of fish on site, comprised of two year-classes, would be approximately equal to the APL), while a single-year-class farm would stock its entire APL every second year. The drop in price for farmed salmon (see above) was another factor in the increase in stocking per farm, as this meant that more fish had to be grown for a farm to be economically viable. Currently, the average stocking rate per farm is ~400 000 smolts, but (since 2006) farms can only stock every 3 yr. The large interannual fluctuations in average stocking rates in recent years are largely due to differences in stocking rates per farm among ABMAs (Fig. 16). The highest average stocking rates since 2006 were in 2008 and 2011 – years when ABMA 3a & 3b stocked.

GROWOUT TIMES AND HARVEST WEIGHTS

In 1987 and 1988 the average harvest weight for farmed salmon in SWNB was estimated to be 3.6 kg (head-on gutted) after a marine growout time of 18-20 months, with average projected harvests of 40 t per farm for the 1986 year-class and 85 t per farm for the 1987 year-class (FGA & WGA 1988); at that time most farms were multi-year class operations, stocking and harvesting every year. In a study at 20 farms that stocked 1995 year-class salmon (3 cages sampled per farm), the average harvest weight was found to be ~4.3 kg after an average marine growout time of ~21 months (Peterson et al. 2001). Using harvest data from that study, and an estimated average stocking rate of 85 000 salmon per farm for the 1995 year-class (see Fig. 14), the average harvest per farm that stocked this year-class was estimated to be ~300 t; most farms were still multi-year-class operations at that time (i.e. harvesting every year). Currently, harvest weights are usually 4-5 kg and marine growout times are usually 16-24 months (Doane Raymond & ARA 1998; Stewart 2001; CMC & Ridler 2009). Average harvests per farm have increased to ~1 500 t, but harvests occur only once every 3 yr at each farm (single-year-class farming on a 3-yr cycle).

TRENDS IN SELECTED FARM CHARACTERISTICS

Cage types

Salmon farming in SWNB is conducted in net cages, suspended from floating collars. The types of cages have changed since the industry began (Fig. 17 & 18). Initially all SWNB farms used cages with wooden collars, adapted from cages used in Norway (Anderson 2007). The most common early design (known as the Malloch cage, after its developer, John Malloch, from Campobello Island) was octagonal in shape, with a diameter of 10 m and nets 4-6 m deep, holding ~2 500 fish. Cages with square and rectangular wooden collars were used at some farms, and larger 10 and 12-sided wooden collars were later developed. However, farms in SWNB

started using non-wooden cages in the latter half of the 1980s. The last wooden cages were taken out of service in 2009.

Cages with square steel collars, 12-15 m wide, holding 3 000 – 5 000 fish per cage, were first used in 1985 and were at >20 farms in the early 1990s. Although more expensive to build than wooden cages, metal cages had longer lifespans, lower maintenance costs, and could hold more fish per unit (FGA & WGA 1987); they were also considered to be stronger and thus better able to withstand storms and sea conditions in more exposed locations. Another reason for the switch from wooden cages was that, following the ISA outbreak in the late 1990s, it was recommended that the use of wood be phased out in SWNB (as had been recommended in Norway at ISA positive farms), because of the difficulties in disinfecting wooden structures (WGA & CanTox Inc. 1998).

A few farms used cages with square plastic collars starting in 1986, but this cage type never became widely used. Circular plastic (high density polyethylene) collars were first used in SWNB in 1987 and are now the dominant type, due to their low cost and ease of construction (Anderson 2007). Furthermore, the Peterson et al. (2001) study found that growth rates and feed conversion ratios were better in plastic circular cages than in square steel cages. The most common sizes of circular cages currently in use are 70-100 m in circumference (22-32 m diameter), holding 12 000 – 40 000 fish per cage. Net depths in SWNB range from 6-15 m (mostly 8-12 m); net depths are restricted by the relatively shallow waters at most farm locations (see below). Recently some farms have installed cages with circular collars 150 m in circumference (48 m diameter); these cages have about double the volume of the 100 m cages.

Various other cage types have been tried in SWNB. Four cages with octagonal steel collars (80 m in circumference) were used between 1993 and 2012 (at three different farms), but are no longer in use. OceanSpar AquaSpar™ anchor-tensioned fish pens were used at two farms between 1996 and 2004. Trials have also been conducted with waterproof bag cages and submersible cages.

Farm ages

The distribution of farm ages among ABMAs (Fig. 19) reflects the geographic trends shown in Fig. 9 & 10. The Letang area (ABMA 2a) has mostly older farms, while the Maces Bay area (ABMA 3a) has mostly newer farms. Summary statistics (average, median, minimum, and maximum ages) for all finfish leases in 2012, active salmon farms in 2010-2012, and inactive farms in 2010-2012 are shown in Table 1. The average and median ages are all ≥17 yr, a reflection of the paucity of new farms during the last 10 yr (Fig. 8). The higher average and median ages for inactive farms (21 and 22 yr, respectively) indicate that a higher proportion of inactive farms are older (compared to active farms).

Lease areas

New farms receiving government financial assistance to start during 1984-1987 were initially allocated small leases of 0.40 ha to hold 1 to 4 cages on a trial basis, with the understanding that lease areas would need to increase later. At that time, Henderson (1985) estimated that an economically viable farm (holding a total of 60 000 fish) would require a lease area of 2 ha.

Average and median areas of active leases have increased over time (Fig. 20), partly due to the larger size of newer farms and partly because of boundary expansions of many older farms. Changes in the economics of fish farming mean that small leases are now less viable (Chang et al. 2014). Summary statistics (average, median, minimum, and maximum areas) for all finfish leases in 2012, active salmon farms in 2010-2012, and inactive farms in 2010-2012 are shown in Table 1. The total area for all finfish leases in 2012 is 1 662 ha and for active salmon farms in 2010-2012 the total area is 1 214 ha. The lower average and median areas for inactive farms indicate that a higher proportion of inactive farms are smaller in area (compared to active farms).

Lease areas (of currently active farms) vary among ABMAs (Fig. 21). The Deer and Campobello Island area (ABMA 1-south) and the Letang area (ABMA 2a) have many small, older farms. Lease areas are largest in the Maces Bay area (ABMA 3a) and northern Passamaquoddy Bay (ABMA 1-north), where most farms are newer.

Water depths in farm leases

Initially, all farms in SWNB were located in shallow, protected sites, close to shore. The wooden cages used in the early years were only suitable for such locations. As the industry grew, newer farms had to be located in deeper, less protected locations. At the same time, cage technology improved, allowing farms to be located at greater depths, in more exposed sea conditions.

In an early report on salmon farming in Norway, Edwards (1978) noted that there should be a minimum depth of 4-5 m under cages at all stages at the tide, which meant that (with the 4-6 m deep nets used at the time) farms should not be located where there was less than 8-10 m water depth at mean low tide. The initial Regulations under the Aquaculture Act (New Brunswick 1991) stated that a proposed lease could be refused if there was a minimum water depth <8 m at mean low water where any cage was located, and this depth criterion remains in the latest consolidation of the Regulations under the Aquaculture Act (New Brunswick 2013), even though net depths are now greater (mostly 8-12 m). However, site guidelines published by the province in 1993 (NBDFA 1993) recommended that water depths should be at least 13 m at mean low tide to allow at least 5 m clearance below nets typically used at the time, and the 2000 site allocation application guide (NBDAFA 2000b) stated that new farm sites should have a minimum depth of 10 m.

The average and median water depths at active salmon leases increased slightly during the 1980s, but have remained relatively constant since 1995, although the average and median

depths at new farms have generally increased over time (Fig. 22). Summary statistics (average, median, minimum, and maximum depths) at all finfish leases in 2012, active salmon farms in 2010-2012, and inactive farms in 2010-2012 are shown in Table 1. Most SWNB farms are located in relatively shallow waters: the average depth for all finfish leases in 2012 is 14.1 m (below lowest normal tide) and the median is 12.2 m. The average depth at inactive farms (13.1 m) is less than at active salmon farms (14.9 m).

The shallow depths at most farms in SWNB restrict the depths of nets, compared to salmon farming areas in Norway, Chile, British Columbia, and southern Newfoundland (Carroll et al. 2003; Soto & Norambuena 2004; Robson 2006), where farms are mostly located in deep fjords (Table 2). In British Columbia, where water depths at farms are mostly 45-70 m, nets are typically 30 m deep (Robson 2006), compared to 8-12 m net depths at most farms in SWNB. Water depths at farms in SWNB are similar to those reported for Scotland and Tasmania, Australia (Gillibrand et al. 2002; Wildish et al. 2003)

Water depths (at currently active farms) vary among ABMAs (Fig. 23). Average and median depths are greatest in northern Passamaquoddy Bay (ABMA 1-north) and in the Maces Bay area (ABMA 3a), and are shallowest around Grand Manan Island (ABMAs 2b & 3b).

Predicted water current speeds

In 1984 all farms were in locations with low predicted mean surface current speeds. The cage technology at the time did not allow cages to be placed at high energy sites. However, sites with low current speeds are more likely to be depositional and thus have a greater probability of causing benthic environmental degradation (Chang et al. 2013). Provincial site guidelines published in 1993 (NBDFA 1993) recommended that mean current speeds at sites should be $\geq$5 cm s^{-1} and preferably $\geq$10 cm s^{-1}, to reduce the likelihood of negative environmental impacts, while the 2000 site allocation application guide (NBDAFA 2000b) stated that bottom currents at proposed farms should be $\geq$5 cm s^{-1}. Sites where currents are too strong may also be unsuitable for growing salmon (Edwards 1978). Two farms which were approved in the area between Deer and Campobello Islands in the late 1990s were unsuccessful, apparently because of strong currents.

Since 1990, there has been a slight increase in median, but not average, predicted mean surface current speeds over time at all active farms, as well as at new farms (Fig. 24). Summary statistics (average, median, minimum, and maximum predicted mean surface current speeds) at all finfish leases in 2012, active salmon farms in 2010-2012, and inactive farms in 2010-2012 are shown in Table 1. Average current speeds are slightly higher at inactive farms than at active farms, while median speeds are slightly higher at active farms. Thirty-nine percent of active salmon farms in 2010-2012 have predicted mean surface current speeds >10 cm s^{-1}. In comparison, Carroll et al. (2003) reported that only 10% of Norwegian salmon farms had average current speeds >10 cm s^{-1}.

Predicted mean surface current speeds (at currently active farms) vary among ABMAs (Fig. 25). Northern Passamaquoddy Bay (ABMA 1-north) has the lowest average and median current speeds. The individual farms with the highest predicted current speeds are found around the southern end of Deer Island (in ABMA 1-south).

It must be noted that these current speed analyses are based on model predictions, because adequate current meter records (≥30 d) are not available for most farms, especially older sites. Furthermore, the predictions were based entirely on the M2 tidal constituent. Although the M2 is the principal tidal constituent in SWNB, other constituents and wind will influence water circulation. Research is currently underway at the DFO St. Andrews Biological Station to improve circulation model predictions for SWNB.

Distances of farms from shore

The average and median distances from shore (the shortest distance from the approximate farm centre to the shore at high tide) for all active farms have increased slightly over time, as have the average and median distances from shore for new farms (Fig. 26), although the two farms approved in 2010-2012 were both <400 m from shore. However, 90% of currently active salmon farms are still located within 1 km of shore. Summary statistics (average, median, minimum, and maximum distances from shore) for all finfish leases in 2012, active salmon farms in 2010-2012, and inactive farms in 2010-2012 are shown in Table 1. Average distances to shore are considerably higher than medians, indicating that many farms are located at short distances from the shore. The average and median distances to shore at active farms are much higher than at inactive farms, indicating that a higher proportion of inactive leases are closer to shore (see Fig. 9).

Distances from the shore (for currently active farms) vary among ABMAs (Fig. 27). The average and median distances are greatest in northern Passamaquoddy Bay (ABMA 1-north) and are smallest in the Letang area (ABMA 2a), where all farms are located within 500 m of the shore.

Distances between neighboring farms

Before 1985, there were few farms, and they were widely separated. Because it was felt that there was only a small area suitable for salmon farming in SWNB, it was decided to allow a high density of farms. The guideline for the minimum distance between farms was set at only 300 m (Henderson 1985), although existing growers felt that this distance was too small (Anderson 2007). Regulations under the Aquaculture Act, first introduced in 1991 (New Brunswick 1991) and consolidated in 2013 (New Brunswick 2013) state that a proposed new farm or a proposed boundary amendment can be refused if it is within 300 m of another farm. However, despite the guideline and regulations, some older farms are located <300 m from neighboring farms. The average and median distances between nearest neighboring farms decreased as the number of farms increased in the 1980s, but have remained relatively constant since 1990 (Fig. 28). Since 1990, 60-80% of farms have had nearest neighbors <1 000 m away. In most other salmon

farming areas, separation distances between farms are usually 1 km or more (Stewart 1998), although these are not mandatory, except in Chile, where current regulations require that new salmon farms be at least 3 km from other farms (Buschmann et al. 2009).

The average distance between nearest neighboring farms for all 92 finfish leases in 2012 is 880 m and the median is 490 m (range: 50 – 5 100 m). For the 59 active salmon farms in 2010-2012, the average distance between nearest neighbors is 1 120 m and the median is 800 m (range: 120 – 5 100 m). The increase in the number of inactive farms in recent years has resulted in substantially greater average and median distances between active nearest neighbors.

Distances between nearest neighbors (for currently active farms) vary among ABMAs (Fig. 29). The average and median distances between nearest neighbors are smallest in the Letang area (ABMA 2a) and eastern Grand Manan Island (ABMA 2b), and largest in the Maces Bay area (ABMA 3a) and northern Passamaquoddy Bay (ABMA 1-north).

The high density of farms in the Letang area (Fig. 30) mean that most farms in this area are limited in their ability to expand. In 2011 three leases were deleted from this area, to allow expansions of three adjacent leases.

Sediment types under farms

A high percentage of silt-clay in seafloor sediments under a farm is indicative of depositional conditions, which can increase the likelihood of a build-up of organic wastes under the farm (Wildish et al. 1990). Initially, most farms in SWNB were located over predominantly fine sediments (>66% silt-clay), but the proportion of active farms located over predominantly fine sediments has decreased over time (Fig. 31). The proportion of new farms with >66% silt-clay in sediments decreased up to the early 2000s; however 5 of the 7 farms that started operating since 2005 were located over sediments with >66% silt-clay (Fig. 31). Among the 92 finfish leases in 2012, 32% have sediments with >66% silt-clay. Among the 59 active salmon farms in 2010-2012, 32% have sediments with >66% silt-clay, while among the 33 other farms (29 inactive and 4 growing non-salmonids), the proportion is 30%.

Seafloor types at farms vary among ABMAs (Fig. 32 & 33). Most farms in northern Passamaquoddy Bay (ABMA 1-north) are located over sediments with high % silt-clay. Most farms around Grand Manan Island (ABMAs 2b & 3b) are located over seafloor with low % silt-clay (predominantly sand, gravel, and/or rock). Farms in southern Passamaquoddy Bay (ABMA 1-south) and the Maces Bay area (ABMA 3a) are located over sediments in all 3 classes, while in the Letang area (ABMA 2a) 5 of the 9 active salmon farms have sediments with >66% silt-clay and the other 4 have 33-66% silt-clay.

FISHERIES LANDINGS IN THE BAY OF FUNDY (NEW BRUNSWICK PORTION)

There are concerns that aquaculture may adversely affect traditional fisheries, due to loss of fishing grounds, environmental degradation of fish habitat, and toxic effects of chemicals used to treat diseases and parasites on fish farms. There has been a decline in total fisheries landings in the New Brunswick portion of the Bay of Fundy (NB Fundy) during the time that salmon farming has developed in SWNB (Fig. 34); most of the NB Fundy catch is within the SWNB area. However, a similar decline has occurred throughout the Maritimes Provinces, including areas where there is no salmon farming. There have been changes in the relative importance of different species in the commercial fisheries. Groundfish landings have decreased in SWNB, as has occurred throughout Atlantic Canada. The herring weir fishery, which is concentrated in SWNB, has declined (but with high interannual variability) during the period of salmon farming growth in this area (Fig. 35), reaching an all-time low in 2012 (DFO 2013a; Power et al. 2013); however herring purse seine catches in SWNB have remained relatively constant. One of the reasons for the decline in the number of herring weirs, especially in the late 1980s and 1990s, was that the owners of many weirs converted their weir leases to salmon farm leases (Stephenson 1990). In contrast to the decreases in herring and groundfish landings, invertebrate (shellfish) landings have increased, primarily due to a 10-fold increase in lobster catches since salmon farming began in SWNB (Fig. 36).

Although total fisheries landings have declined in NB Fundy, the overall value of the fishery has increased, primarily due to the increased landings of lobster, which commands a higher market price than most finfish species (Fig. 37). In 2012 lobster landings represented 73% of the value of all fisheries landings in NB Fundy (DFO 2014b).

There was a fishery for wild salmon in the Bay of Fundy, but due to declining stocks, the commercial fishery was closed in 1983 and the recreational fishery was closed in 1997 (Fig. 38). Despite the salmon fishery closures, returns to salmon rivers in NB Fundy have continued to decline (DFO 2013b). Bay of Fundy salmon stocks are now listed as endangered (COSEWIC 2010). Although wild salmon stocks began declining prior to the start of salmon farming in the Bay of Fundy, there are concerns that salmon farming may play a role in preventing the recovery of the wild stocks, possibly due to the spread of diseases and parasites (especially sea lice) from farmed to wild salmon, genetic interactions (when farmed salmon escape from cages), and ecological interactions (DFO 1999). Salmon farming would be expected to have greatest impacts on the salmon rivers which are closest to the SWNB salmon farming area: the Magaguadavic and St. Croix Rivers (Fig. 1). Wild salmon stocks in both of these rivers are currently at extremely low levels (DFO 2013b). The potential for impacts of salmon farming on salmon returning to the most important salmon river in the area, the St. John River (and its tributaries), may be lower because this river is located further from the salmon farming area (the river discharges to the Bay of Fundy at Saint John; see Fig. 1) and there is less spatial overlap between juveniles and adults from this river with the SWNB salmon farming area (Chang et al. 2011).

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Table 1. Summary statistics for farm age, lease area, water depth, predicted current speed, and distance to shore for finfish farms in southwestern New Brunswick. All = all 92 finfish leases in southwestern New Brunswick in 2012. Active salmon = 59 farms that grew salmon during 2010-2012; these farms had salmon on site for an average of ~20 months (minimum 2 months) during this period. Inactive = 29 farms that were inactive during the entire period 2010-2012. Four other farms grew non-salmonid finfish during 2010-2012.

Parameter	Farm group	Average	Median	Min	Max
Farm age in 2012 (yr)	All	19	19	0	34
	Active salmon	17	17	0	31
	Inactive	21	22	4	34
Lease area (ha)	All	18.1	16.3	2.0	47.3
	Active salmon	20.6	19.8	2.0	47.3
	Inactive	14.2	10.6	3.1	45.2
Water depth: average depth within lease at low tide (m)	All	14.1	12.2	4.5	39.5
	Active salmon	14.9	12.2	5.7	39.5
	Inactive	13.1	12.1	4.5	33.0
Current speed: predicted mean surface speed (cm s^{-1})	All	10.3	7.3	0.8	48.5
	Active salmon	9.7	7.8	0.8	47.6
	Inactive	11.6	6.0	1.4	48.5
Distance to shore from farm centre (m)	All	440	300	70	2 930
	Active salmon	520	370	70	2 930
	Inactive	300	200	80	1 500

Table 2. Water depths at marine salmonid farms in various farming areas.

Farming area	Depth range at farms (m)	Reference
Southwestern New Brunswick	5–40 (mean = 14)	This study
Nova Scotia	5–56 (mean = 14)	Depth data from the Canadian Hydrographic Service (Dartmouth, NS) at currently approved marine salmonid farms
Southern Newfoundland	15–194 (median = 71)	Hamoutene et al. (2013)
British Columbia	mostly 45–70	Robson (2006)
Chile	15–94	Soto & Norambuena (2004)
Norway	75% of farms at 25–75	Carroll et al. (2003)
Scotland	typically 15–30	Gillibrand et al. (2002)
Tasmania, Australia	7–36 (mean = 19)	Wildish et al. (2003)

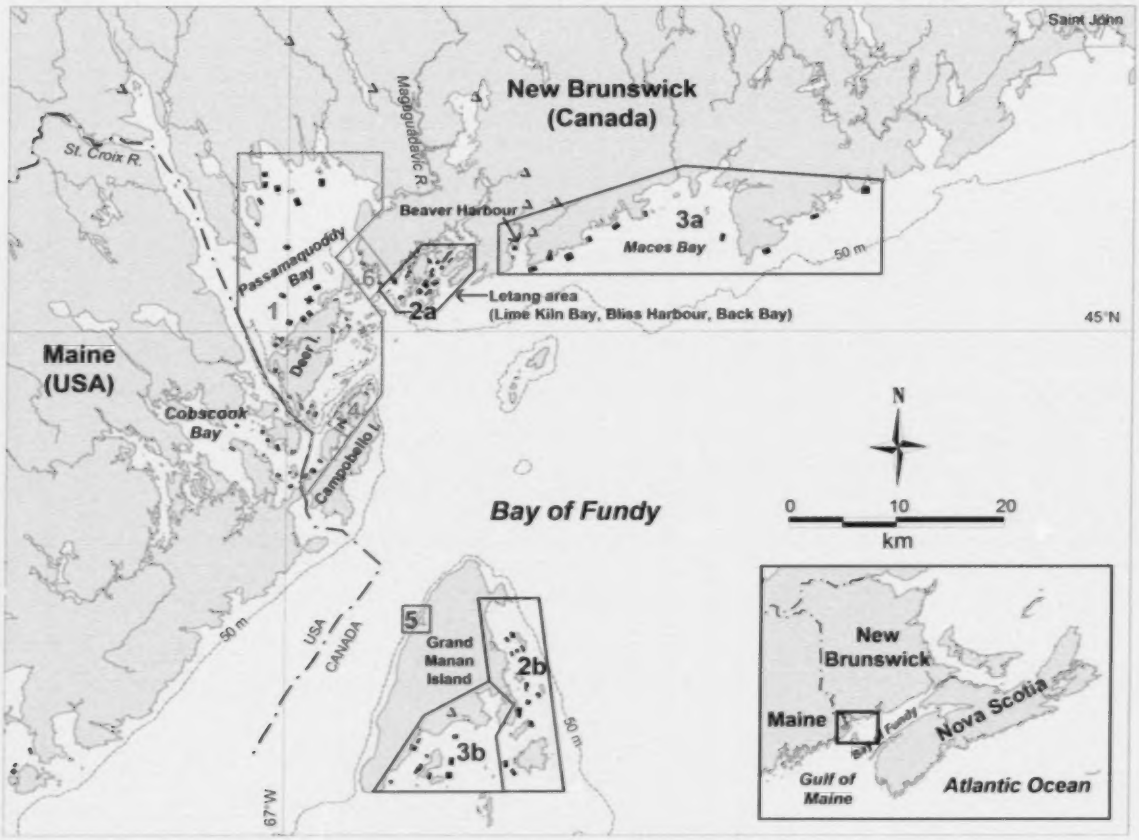


Fig. 1. Map of southwestern New Brunswick and adjacent Maine, showing marine finfish farm leases in 2012 (black polygons) and Aquaculture Bay Management Areas (ABMAs) implemented starting in 2006 (thick outlines); ABMA 4 (on Campobello Island) was incorporated into ABMA 1 in 2010. There was one farm in ABMA 5, but there has been no lease in this ABMA since 2008. The map area also includes 9 of the 13 active commercial salmon hatcheries in New Brunswick in 2012 (green triangles). Data sources: NBDAAF (2014); NBDAA (2007); MDMR (2014); NBDELG (Fredericton, NB).

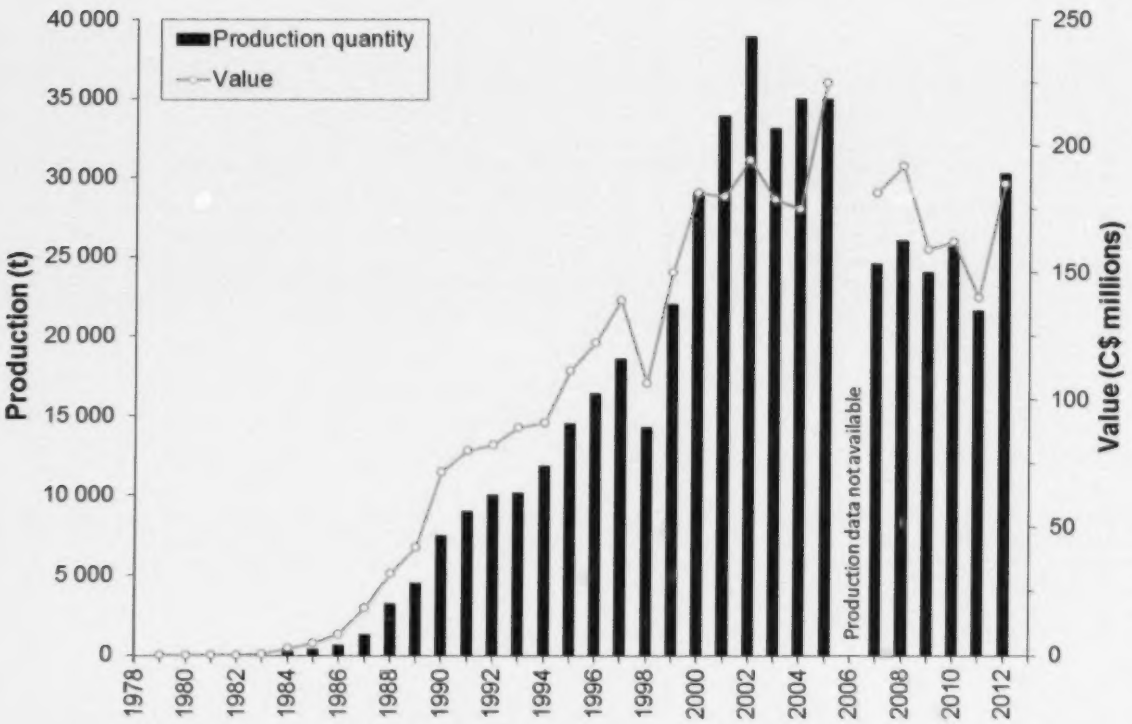


Fig. 2. Production quantity and value of farmed Atlantic salmon in southwestern New Brunswick, 1978-2012. Data are for head-on, gutted fish (excluding hatcheries and processing). Data were not available for 2006. Values are in Canadian dollars (C$). Data sources: DFO (2014a); Statistics Canada (2013); NBDFA (1998).

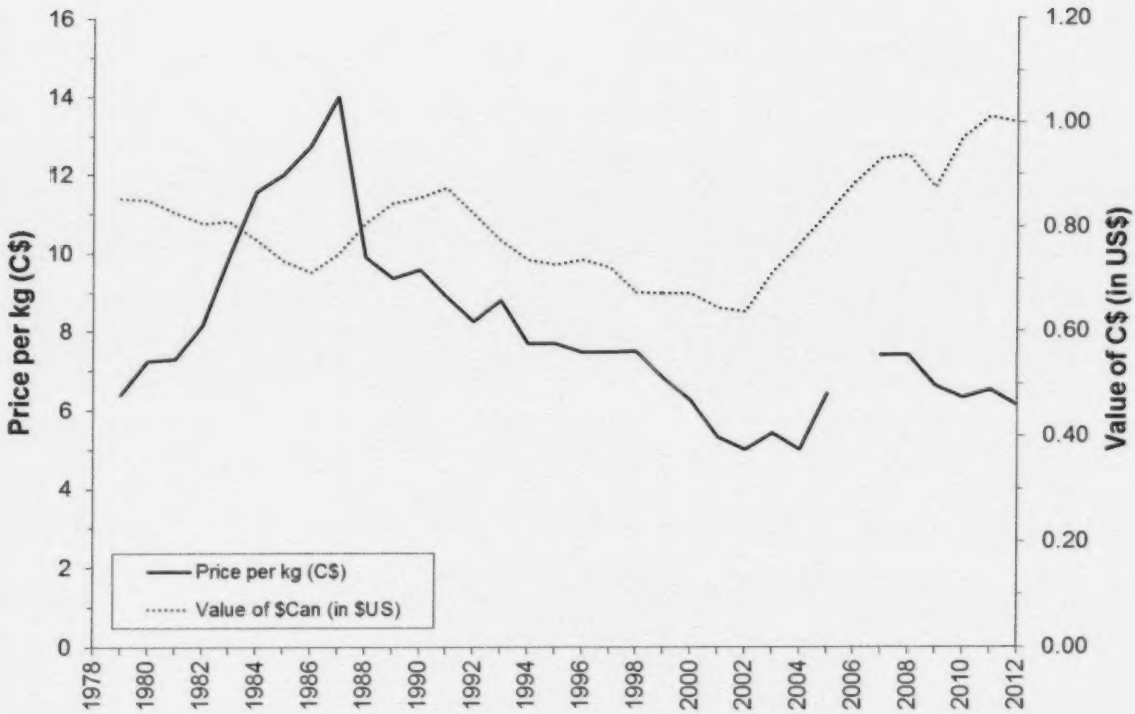


Fig. 3. Price (per kg) of farmed salmon (excluding processing) from southwestern New Brunswick and the value of the Canadian dollar (C$) relative to the United States dollar (US$), 1979-2012. Production data were not available for 2006. Data sources: DFO (2014a); Statistics Canada (2013); NBDFA (1998); exchange rates were obtained from the Bank of Canada website (www.bankofcanada.ca/rates/exchange/).

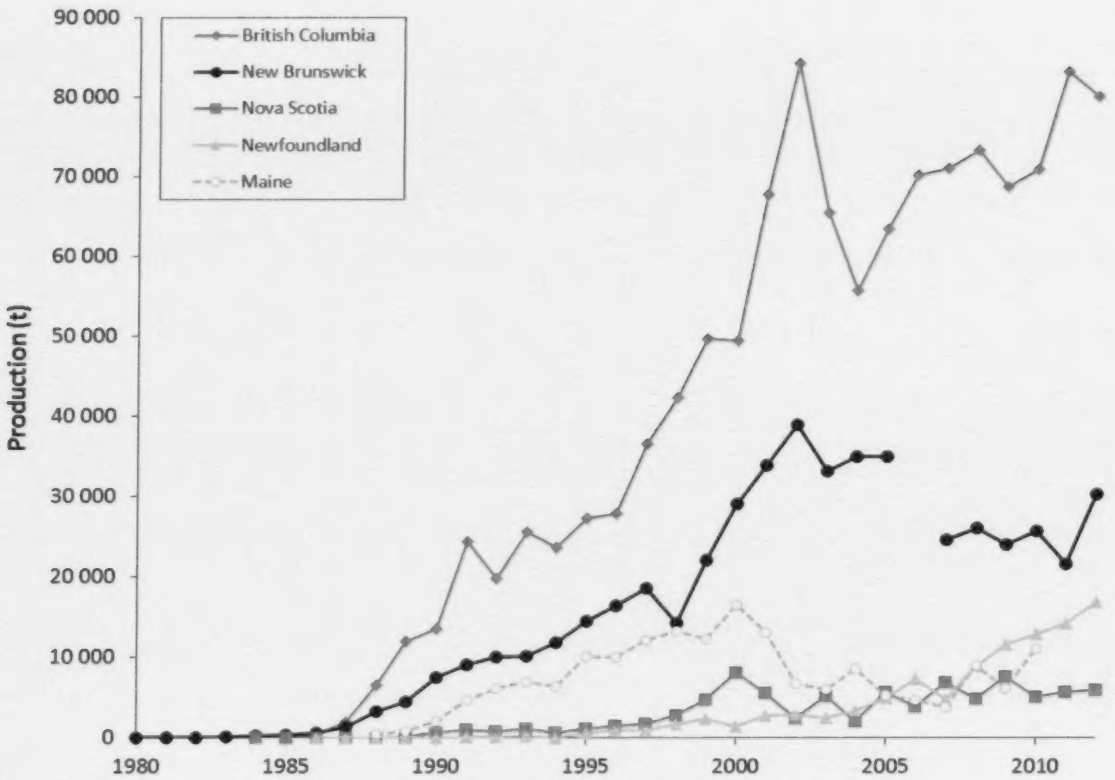


Fig. 4. Salmon mariculture production quantity in Canada (by province) and in Maine, USA, 1980-2012. Figures include mariculture production of Atlantic salmon, Pacific salmon, and marine trout. Data were not available for New Brunswick in 2006 and Maine in 2011-2012. Data sources: DFO (2014a); Statistics Canada (2013); NBDFA (1998); NLDFA (2013); MDMR (2014).

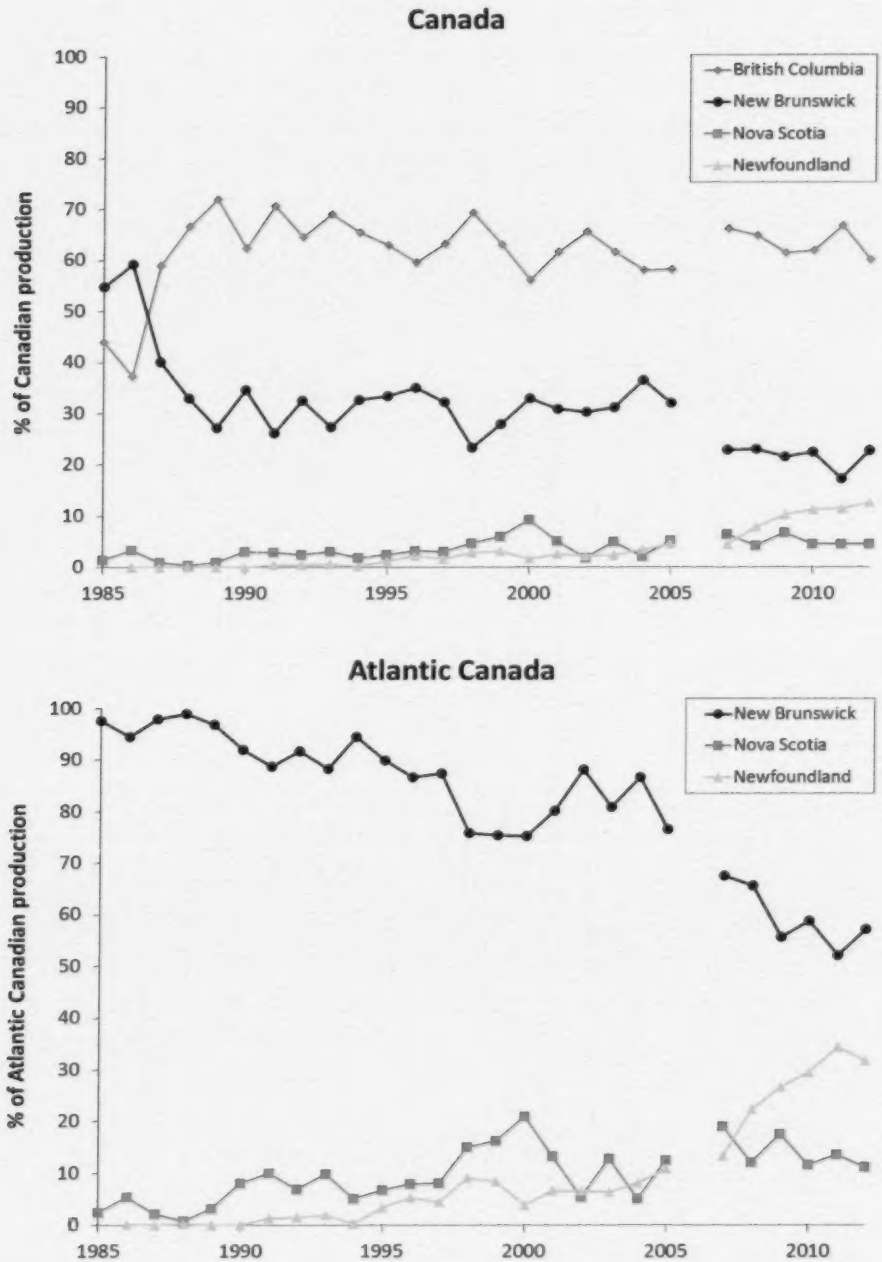


Fig. 5. Percent of salmonid mariculture production quantity by province in Canada (top) and Atlantic Canada (bottom), 1985-2012. Production data were not available for New Brunswick in 2006. Data sources: see Fig. 4.

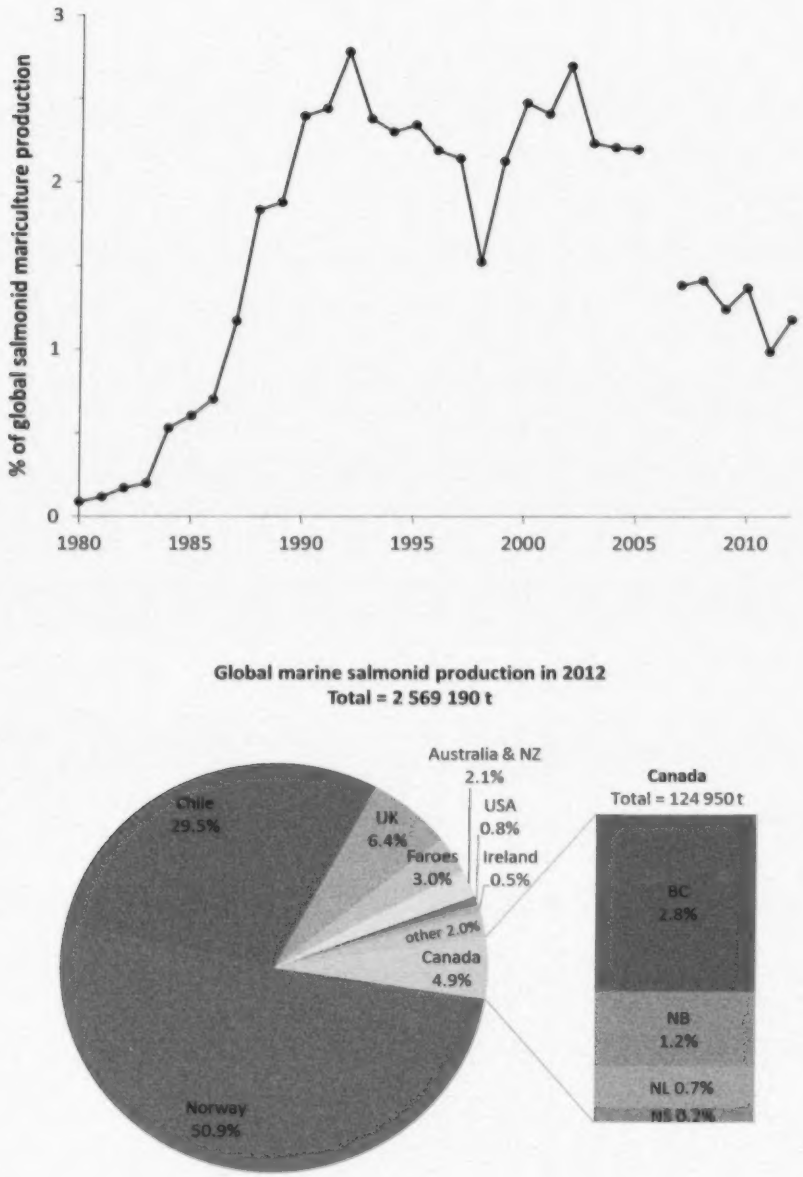


Fig. 6. Salmonid mariculture production quantity in southwestern New Brunswick as a percentage of global production, 1980-2012 (top) and the percentage of global production by country (and by province in Canada) in 2012 (bottom). New Brunswick production data were not available for 2006. Data sources: DFO (2014a); Statistics Canada (2013); NBDFA (1998); NLDFA (2013); FAO (2014).

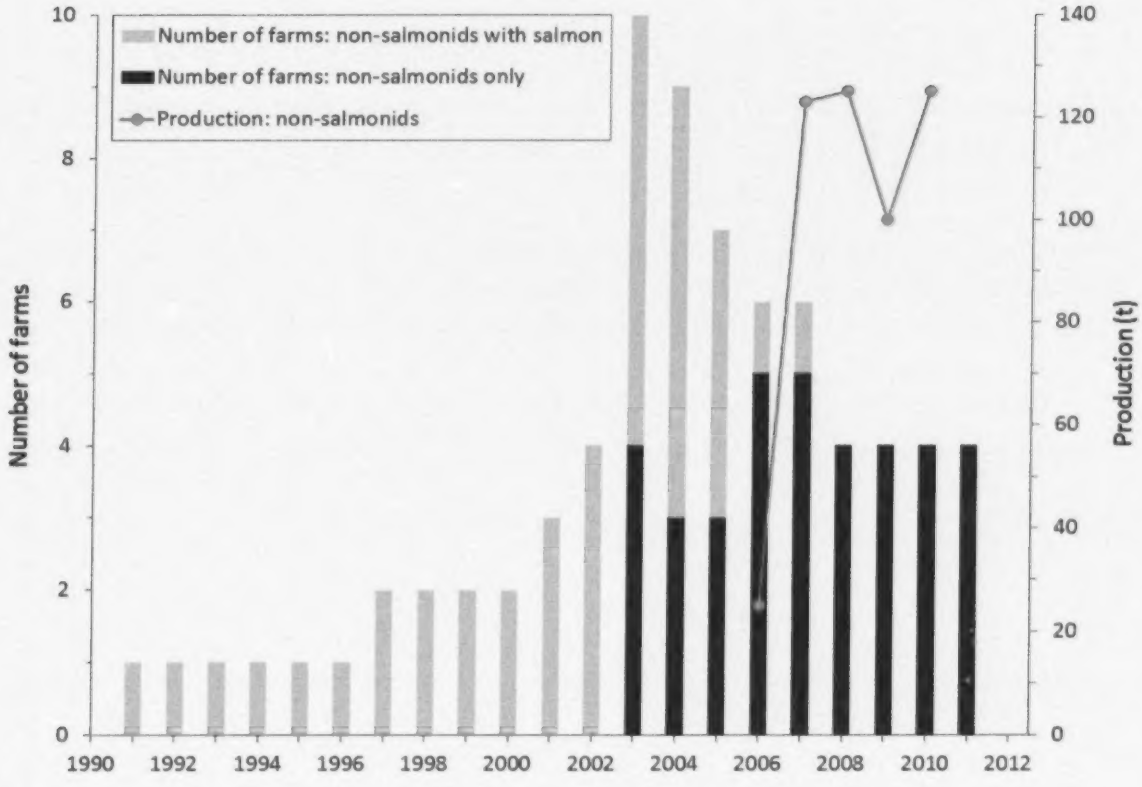


Fig. 7. Number of marine farms growing non-salmonid finfish species in southwestern New Brunswick, 1991-2012 (excluding land-based facilities). The first marine growout trials with non-salmonid finfish species started in late 1991. There were no marine farms growing commercial non-salmonid finfish species in 2012. Also shown are non-salmonid production quantity estimates; these were only available for 2006-2010, and include cod and halibut production at marine farms, as well as sturgeon production at two land-based facilities. Data sources: NBDAAF (2008-2011); NBDAAF (St. George, NB).

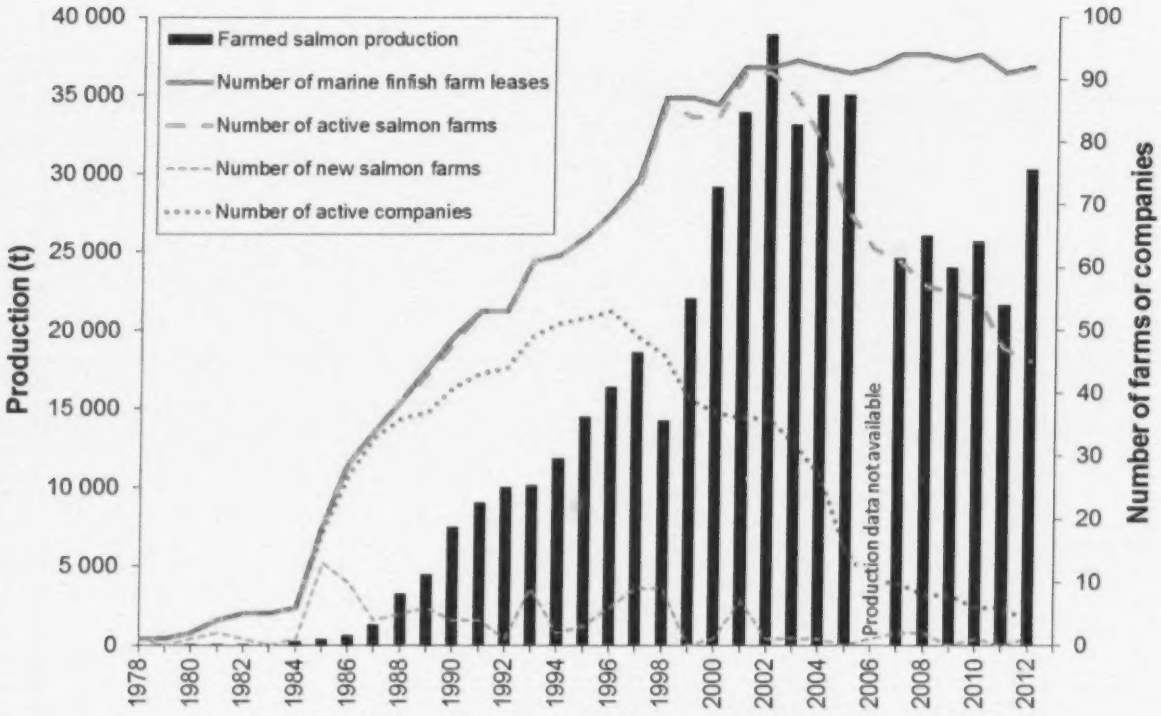


Fig. 8. Numbers of marine finfish leases, operating salmon farms, new salmon farms, and operating companies in southwestern New Brunswick, 1978-2012. Also shown is farmed salmon production quantity per year (data were not available for 2006). Active farms were those that held fish for ≥1 month in a year. New farms are shown in the year when operations started; not included are some farms that started in the 1980s, but failed during their first year (these farms were included if and when successful operations started in subsequent years). Companies that had the same ownership and/or management were combined. Data sources: DFO (2014a); Statistics Canada (2013); NBDFA (1998); NBDAAF (St. George, NB).

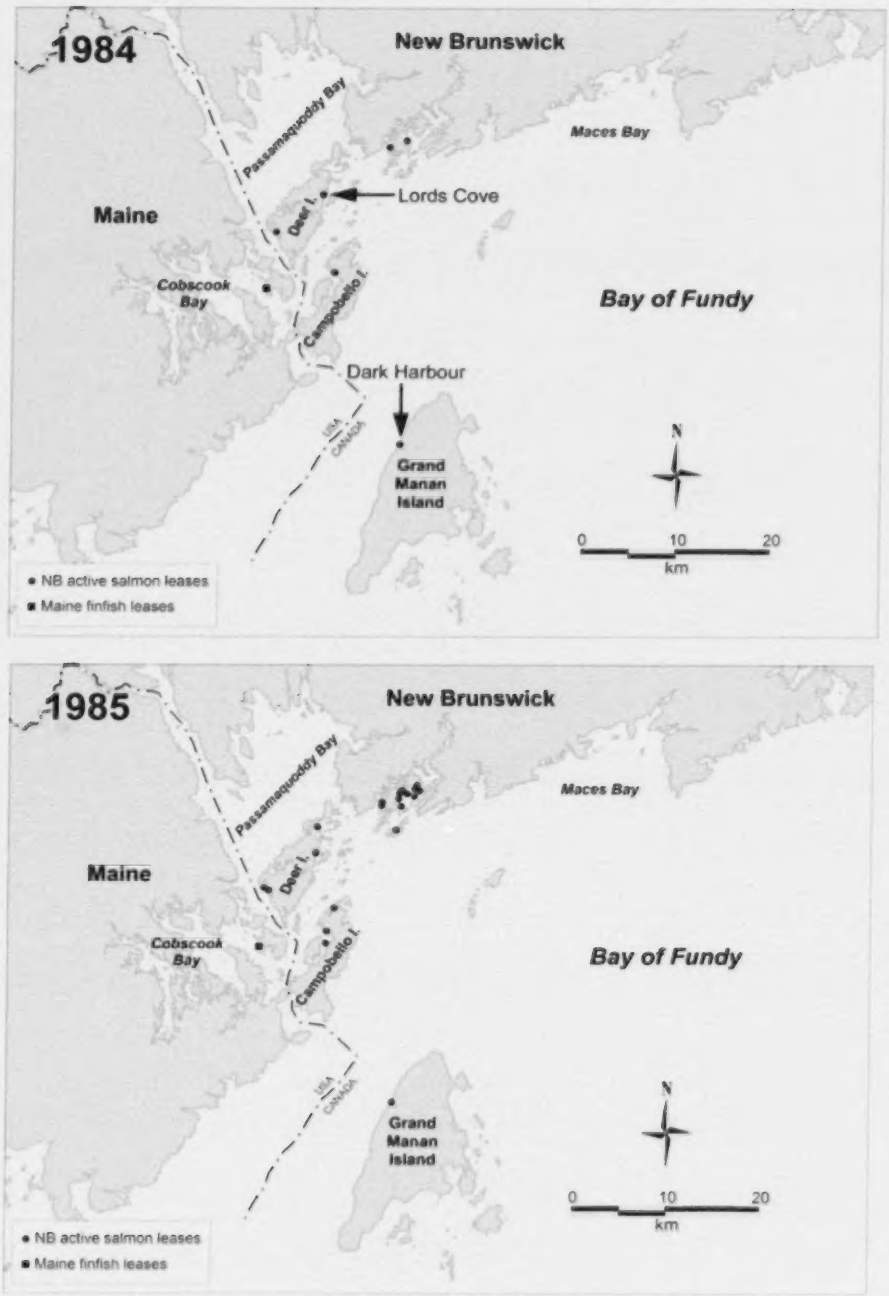
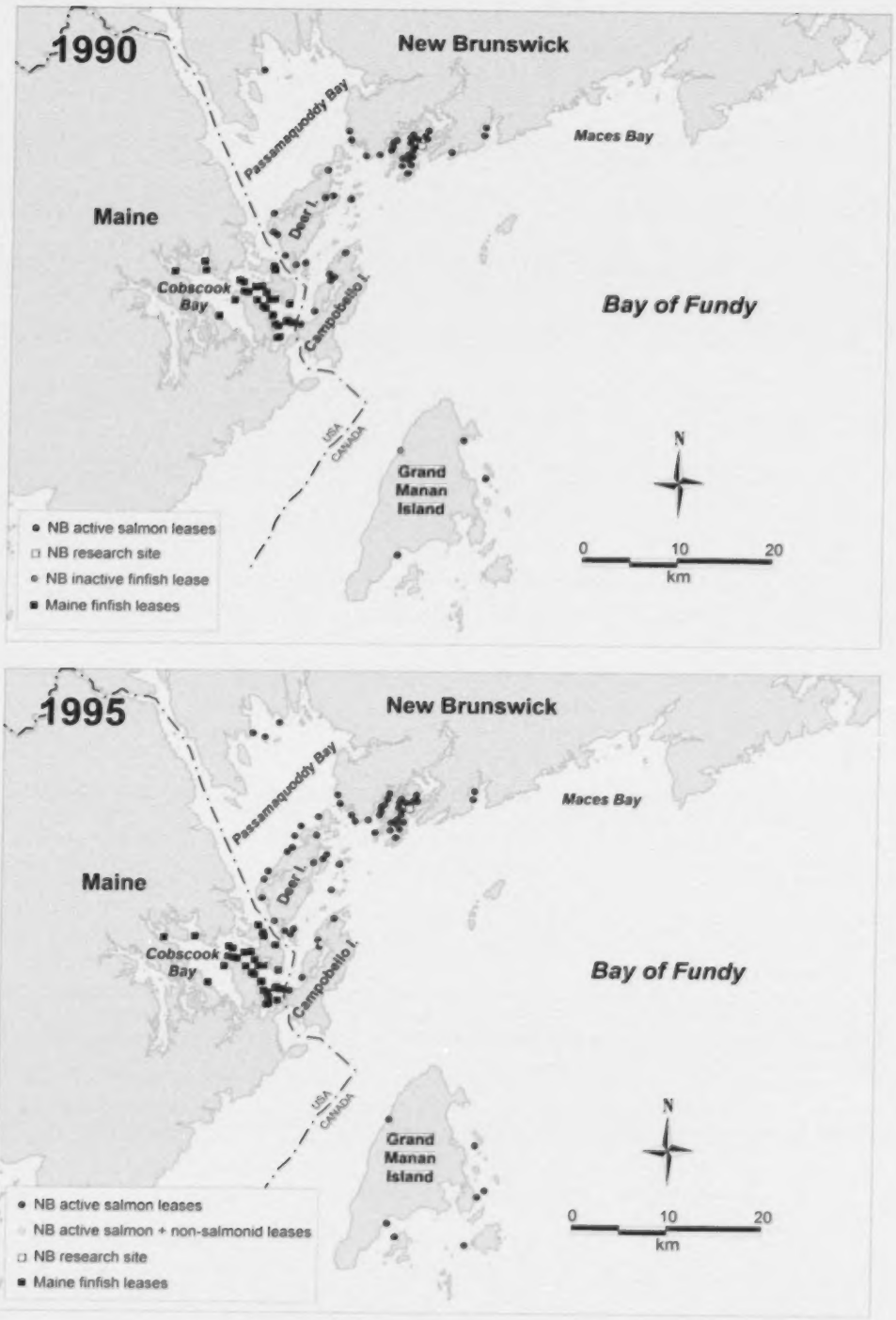


Fig. 9. Finfish leases in southwestern New Brunswick (SWNB) and adjacent Maine, 1984-2012. The first two salmon farms in SWNB were at Lords Cove (1978) and Dark Harbour (1980). IMTA = Integrated Multi-Trophic Aquaculture sites. Data sources: NBDAAF (2014); NBDAAF (St. George, NB); Maine Department of Marine Resources (MDMR) (1990, 2000, 2014); MDMR (West Boothbay Harbor, ME).


1990
New Brunswick
Passamaquoddy Bay
Maces Bay
Maine
Deer I.
Cobscook Bay
Campobello I.
Bay of Fundy
USA
CANADA
Grand Manan Island
NB active salmon leases
NB research site
NB inactive finfish lease
Maine finfish leases
N
0
10
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1995
New Brunswick
Passamaquoddy Bay
Maces Bay
Maine
Deer I.
Cobscook Bay
Campobello I.
Bay of Fundy
USA
CANADA
Grand Manan Island
NB active salmon leases
NB active salmon + non-salmonid leases
NB research site
Maine finfish leases
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Fig. 9 (cont'd).

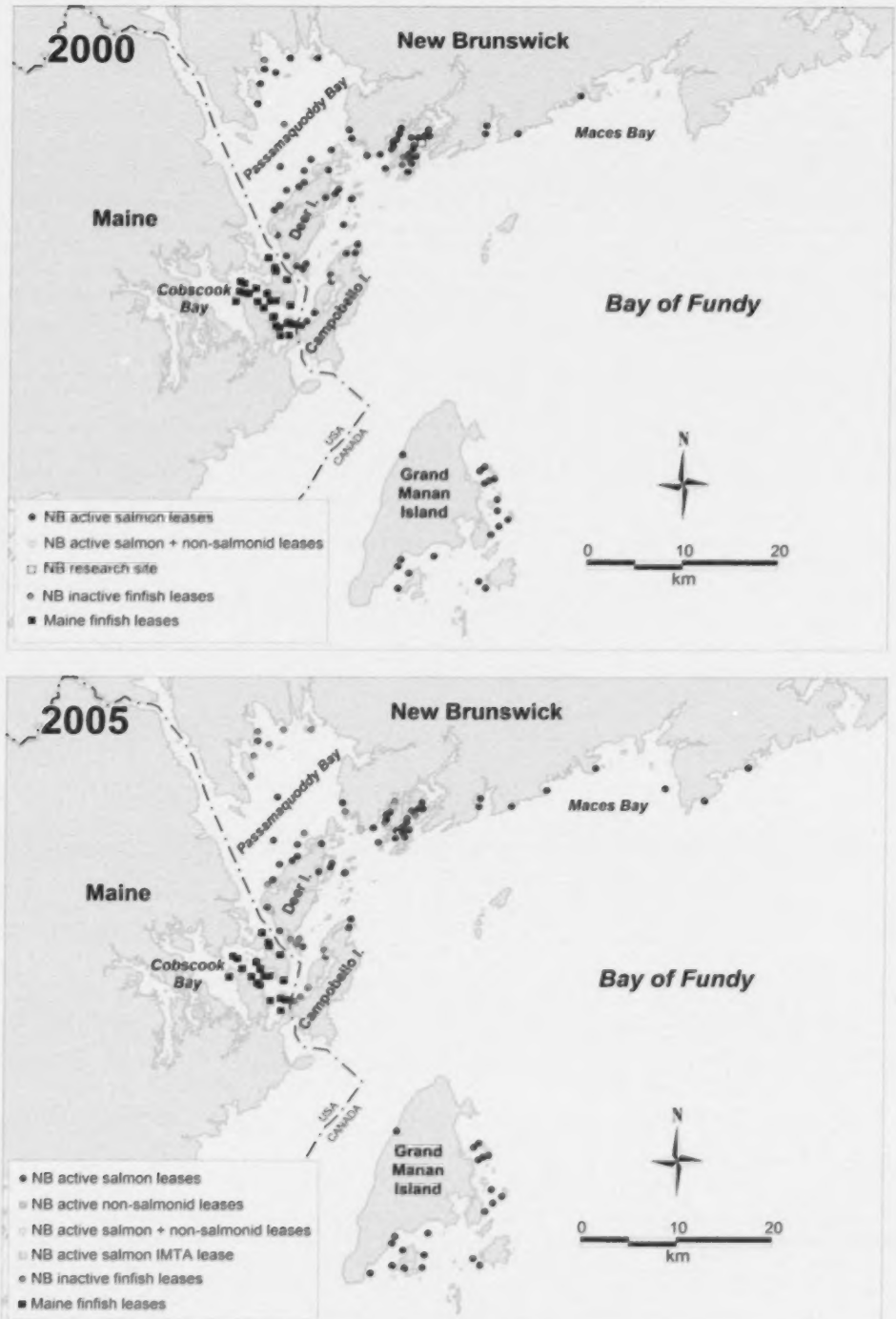


Fig. 9 (cont'd). The salmon IMTA site in 2005 also had haddock.

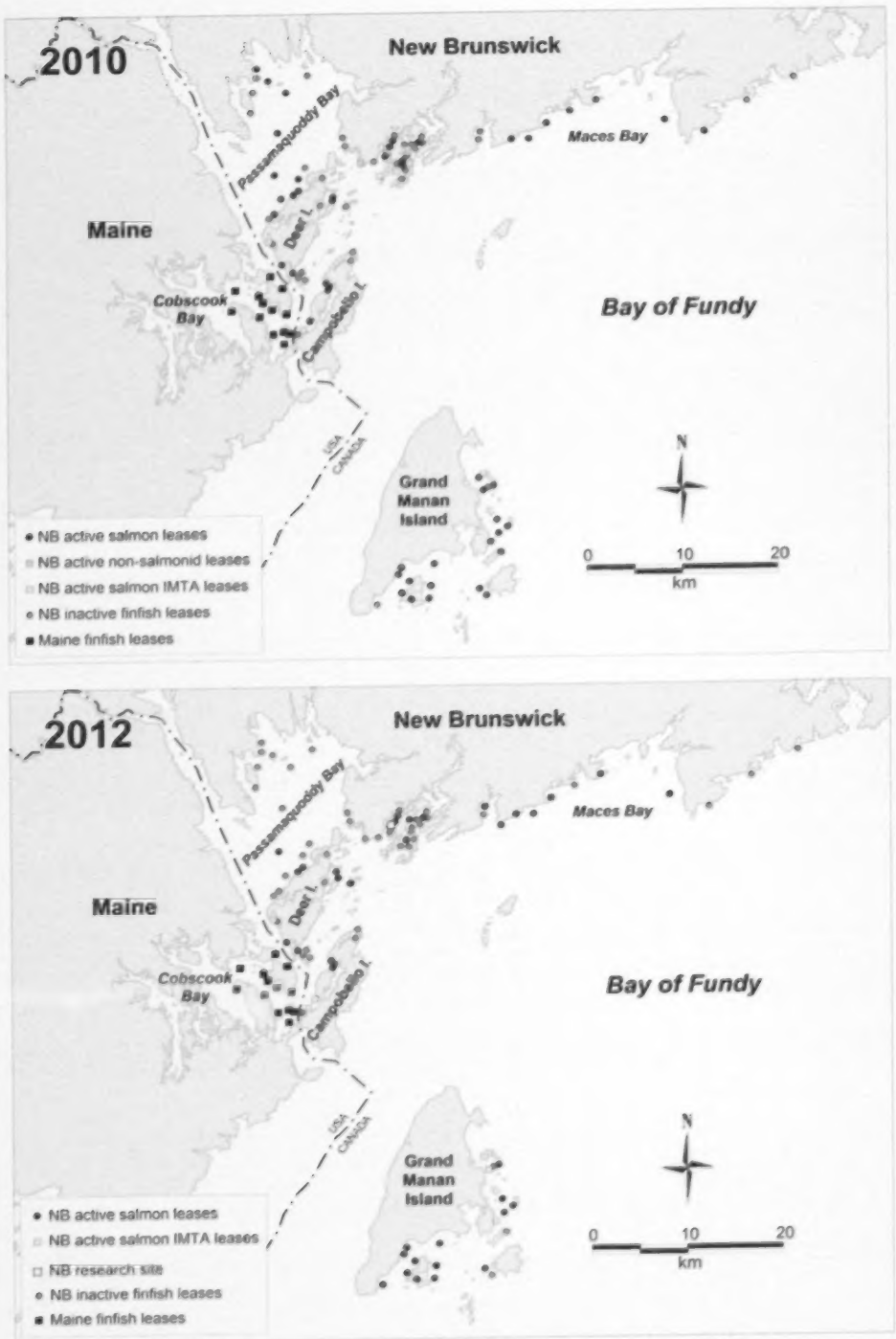
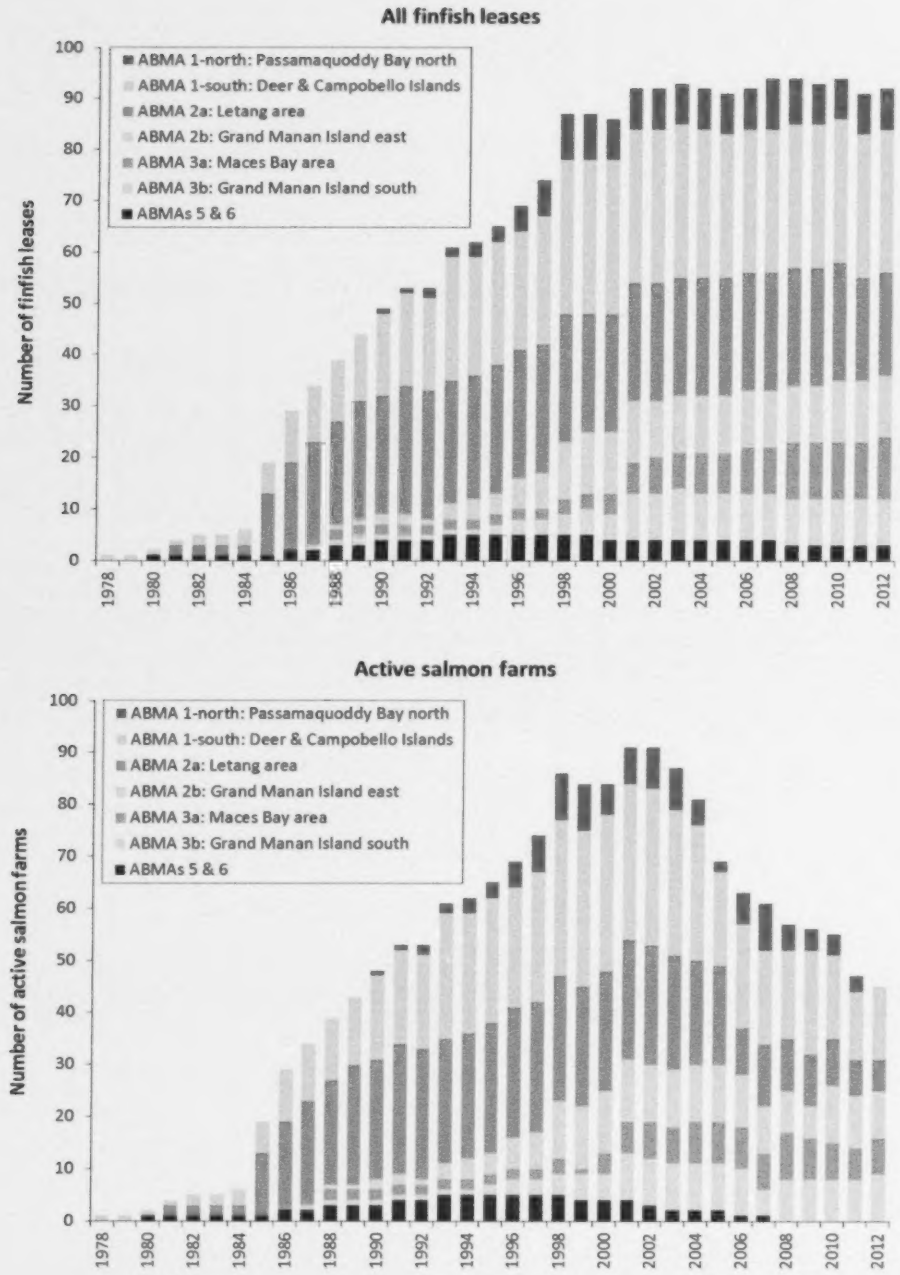


Fig. 9 (concluded).


All finfish leases
Number of finfish leases
ABMA 1-north: Passamaquoddy Bay north
ABMA 1-south: Deer & Campobello Islands
ABMA 2a: Letang area
ABMA 2b: Grand Manan Island east
ABMA 3a: Maces Bay area
ABMA 3b: Grand Manan Island south
ABMAs 5 & 6
Active salmon farms
Number of active salmon farms
ABMA 1-north: Passamaquoddy Bay north
ABMA 1-south: Deer & Campobello Islands
ABMA 2a: Letang area
ABMA 2b: Grand Manan Island east
ABMA 3a: Maces Bay area
ABMA 3b: Grand Manan Island south
ABMAs 5 & 6

Fig, 10. Numbers of marine finfish leases (top) and active salmon farms (bottom) in southwestern New Brunswick, by Aquaculture Bay Management Area (ABMA), 1978-2012. Farms were considered to be active if they held fish for ≥1 month in a year. ABMAs are those implemented in 2006 (Fig. 1), except ABMA 1 has been subdivided into 1-north and 1-south, and ABMA 4 is included within ABMA 1-south. Data source: NBDAAF (St. George, NB).

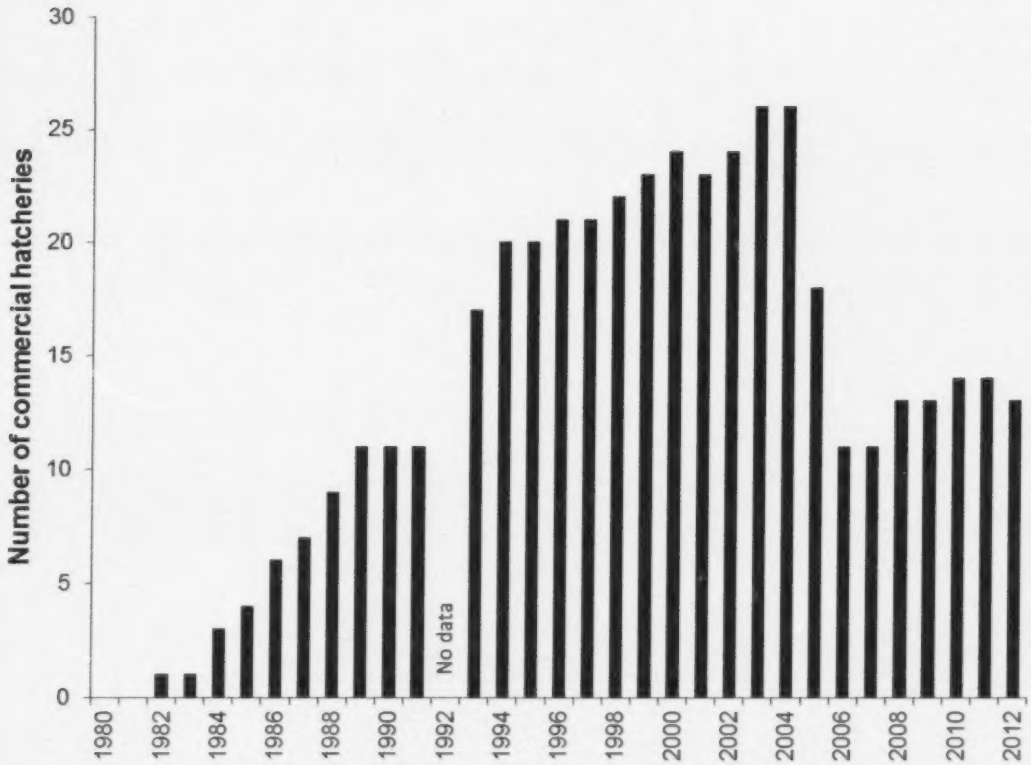


Fig. 11. Estimated number of commercial hatcheries in New Brunswick producing Atlantic salmon smolts for aquaculture, 1980-2012. No estimate was available for 1992. Numbers exclude DFO salmon enhancement and research facilities which supplied smolts for aquaculture from 1978 until the early 1990s. Data sources: Scarratt (1987); Cook (1988); FGA & WGA (1988); Deloitte & Touche (1990); Price Waterhouse Management Consultants (1991); Anderson (2007); CMC & Ridler (2009); NBDAAF (St. George, NB); NBDELG (Fredericton, NB).

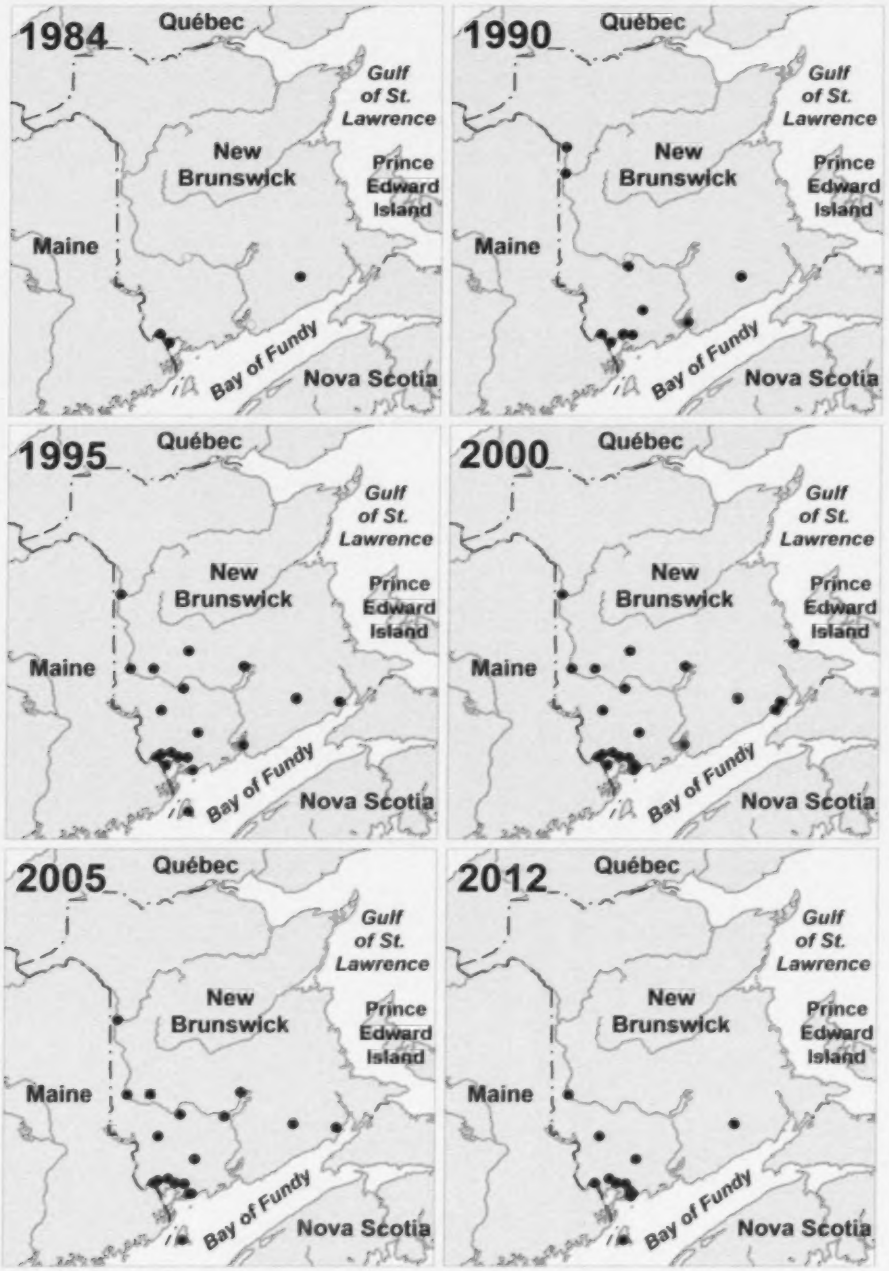


Fig. 12. Locations of New Brunswick hatcheries producing Atlantic salmon smolts for the southwestern New Brunswick aquaculture industry, 1984-2012. Black circles indicate commercial salmon hatcheries. Blue circles indicate DFO hatcheries (Mactaquac and Saint John) that supplied smolts for aquaculture from 1978 to the early 1990s. Hatcheries located outside of New Brunswick are not shown. See Fig. 11 for data sources.

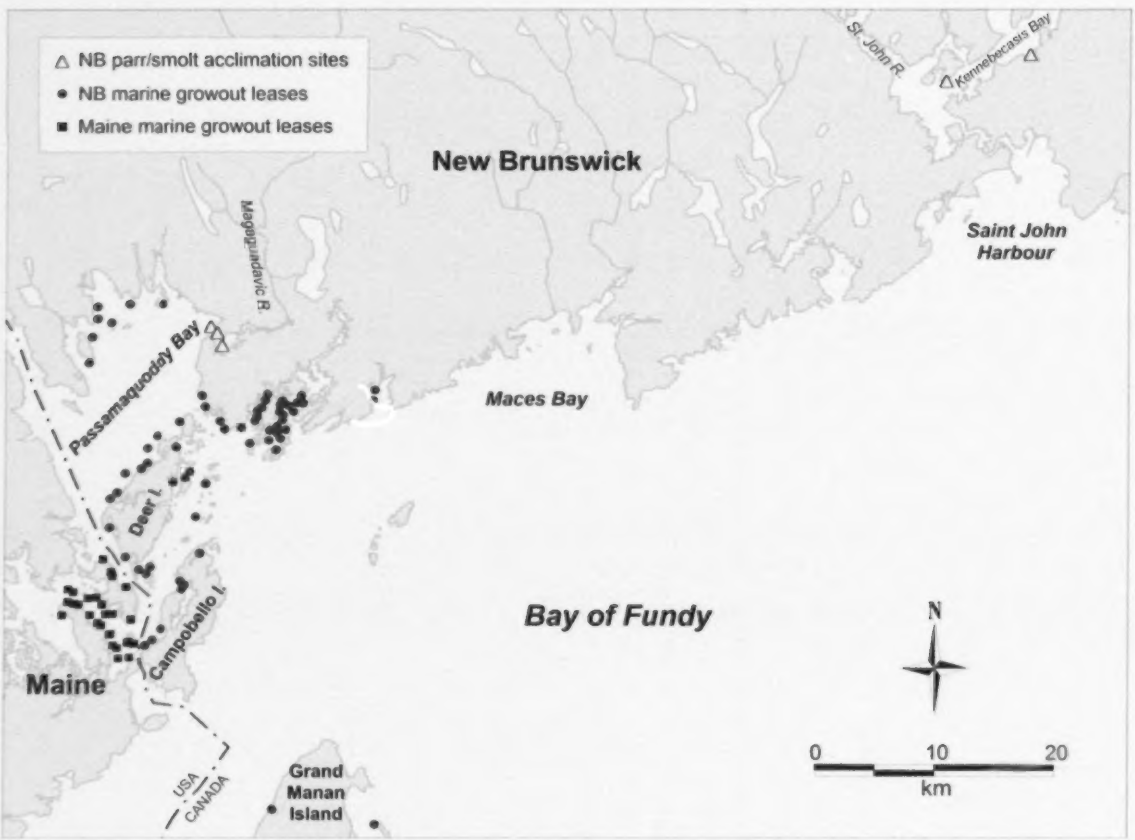


Fig. 13. Locations of 5 parr/smolt acclimation sites in southwestern New Brunswick during 1994-1997. Three were located in the Magaguadavic River estuary and two were in Kennebecasis Bay (near Saint John). Also shown are locations of marine finfish growout leases in 1997. Data source: NBDAAF (St. George, NB).

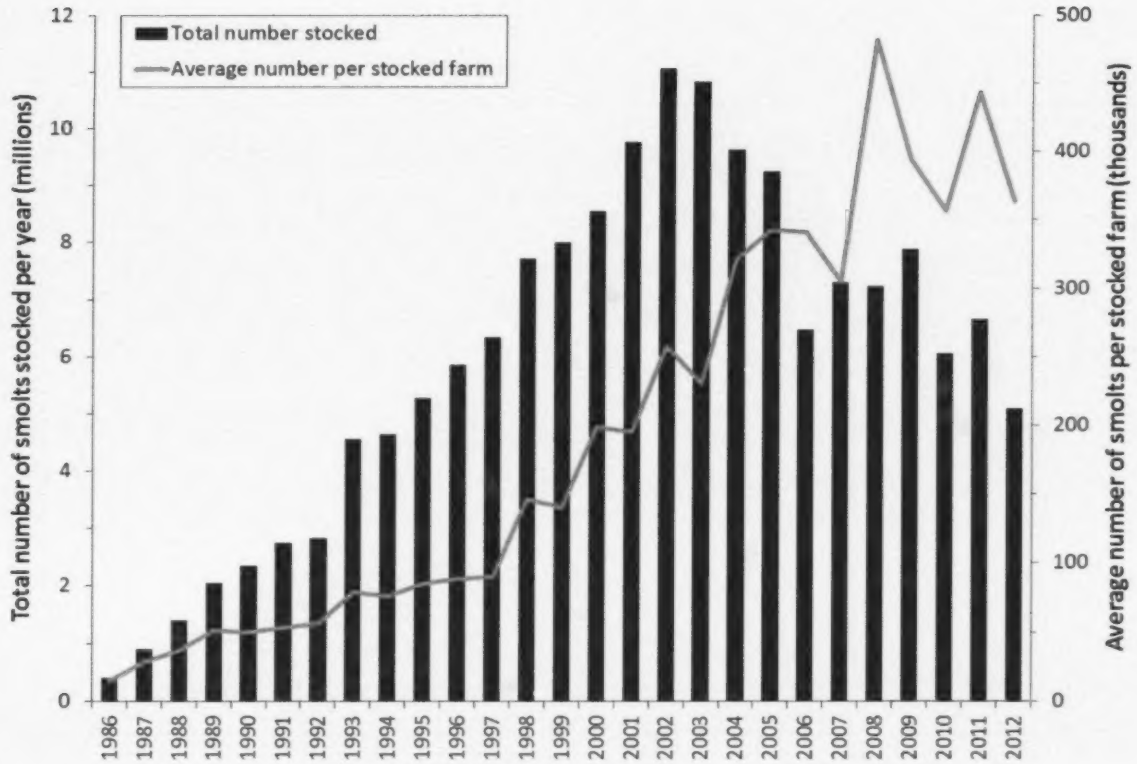


Fig. 14. Estimated number of salmon smolts stocked at salmon farms in southwestern New Brunswick, 1986-2012. Numbers are for transfers of smolts from hatcheries to marine cage sites. Stocking data were not available for most farms during 1990-1997 and many farms during 1998-2004; in these cases, stocking rates were estimated using the allowable production levels (see text for details). Also shown is the estimated average number of smolts per stocked farm in each year. Data sources: FGA & WGA 1988; NBDAAF (St George, NB); DFO (St. George, NB).

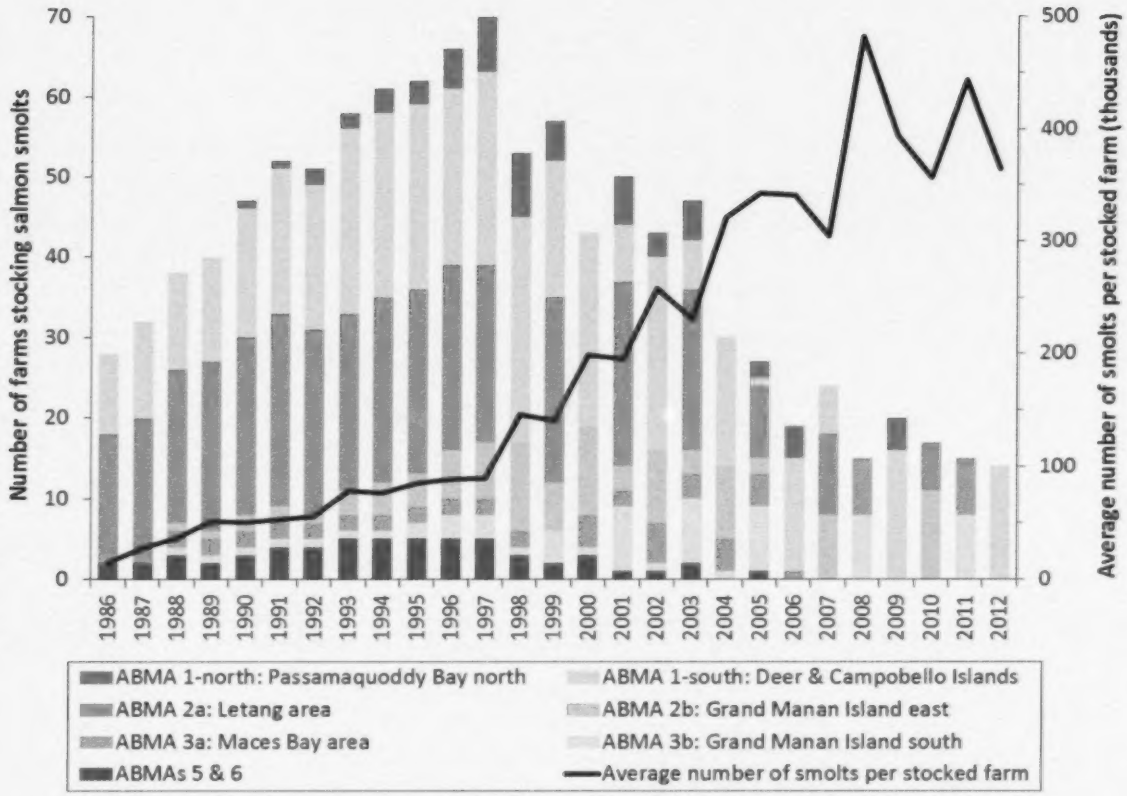


Fig. 15. Estimated number of farms that stocked salmon smolts, by Aquaculture Bay Management Area (ABMA), 1986-2012. Numbers are for transfers of smolts from hatcheries to marine cage sites; transfers between marine sites are not included. Until 1997 most farms were multi-year-class operations, stocking every year. By late 2002 all farms were single-year-class operations, on a 2-year stocking cycle. A 3-year stocking cycle was implemented starting in 2006. Also shown is the estimated average number of smolts per stocked farm in each year. ABMAs are those implemented in 2006 (Fig. 1), except ABMA 1 has been subdivided into 1-north and 1-south, and ABMA 4 is included within ABMA 1-south. Data sources: FGA & WGA (1988); NBDAAF (St. George, NB); DFO (St. George, NB).

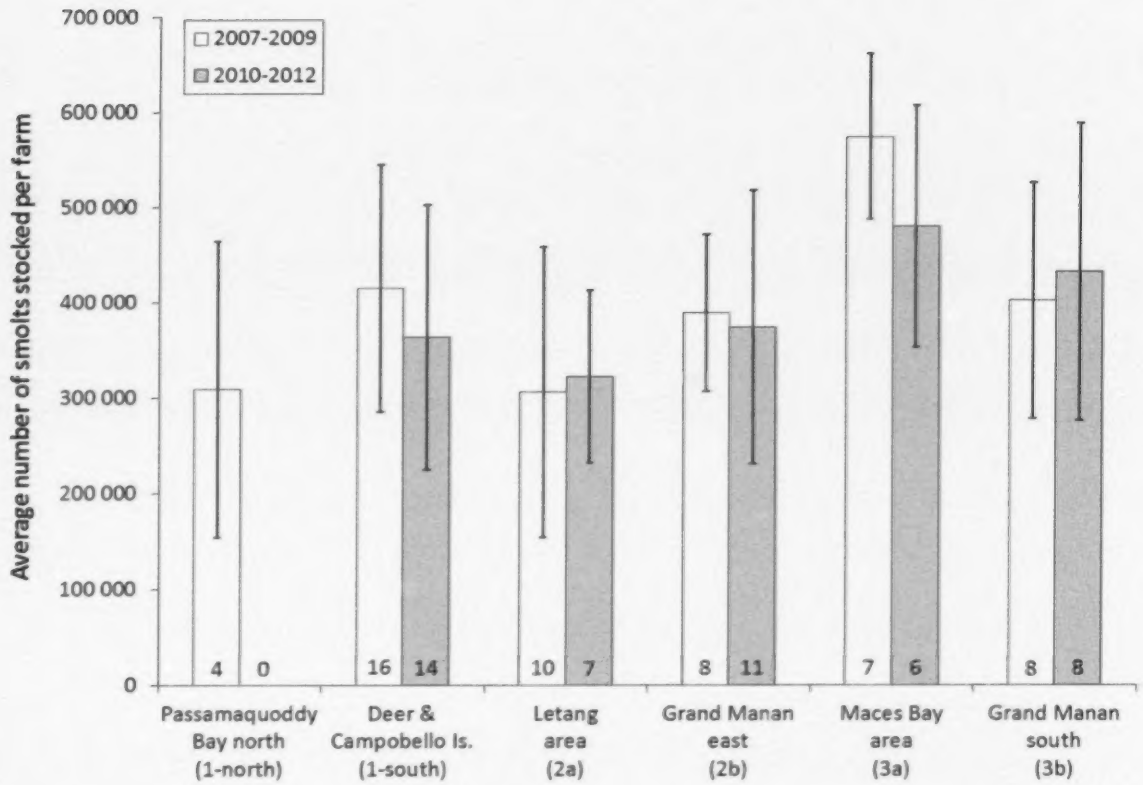


Fig. 16. Average stocking rates in each Aquaculture Bay Management Area (ABMA) for salmon farms that stocked during 2007-2009 and 2010-2012. ABMAs are those implemented in 2006 (Fig. 1), except ABMA 1 has been subdivided into 1-north and 1-south, and ABMA 4 is included within 1-south. The data shown include stocking in ABMA 1 in 2009 and 2012 (there was no stocking in ABMA 1-north in 2012); stocking in ABMA 2a & 2b in 2007 and 2010 (also includes one farm in ABMA 2a that stocked in 2011); and stocking in ABMA 3a & 3b in 2008 and 2011. Vertical lines represent ± 1 standard deviation. Numbers above the x-axis indicate the number of farms stocked with smolts. Data sources: NBDAAF (St. George, NB); DFO (St. George, NB).

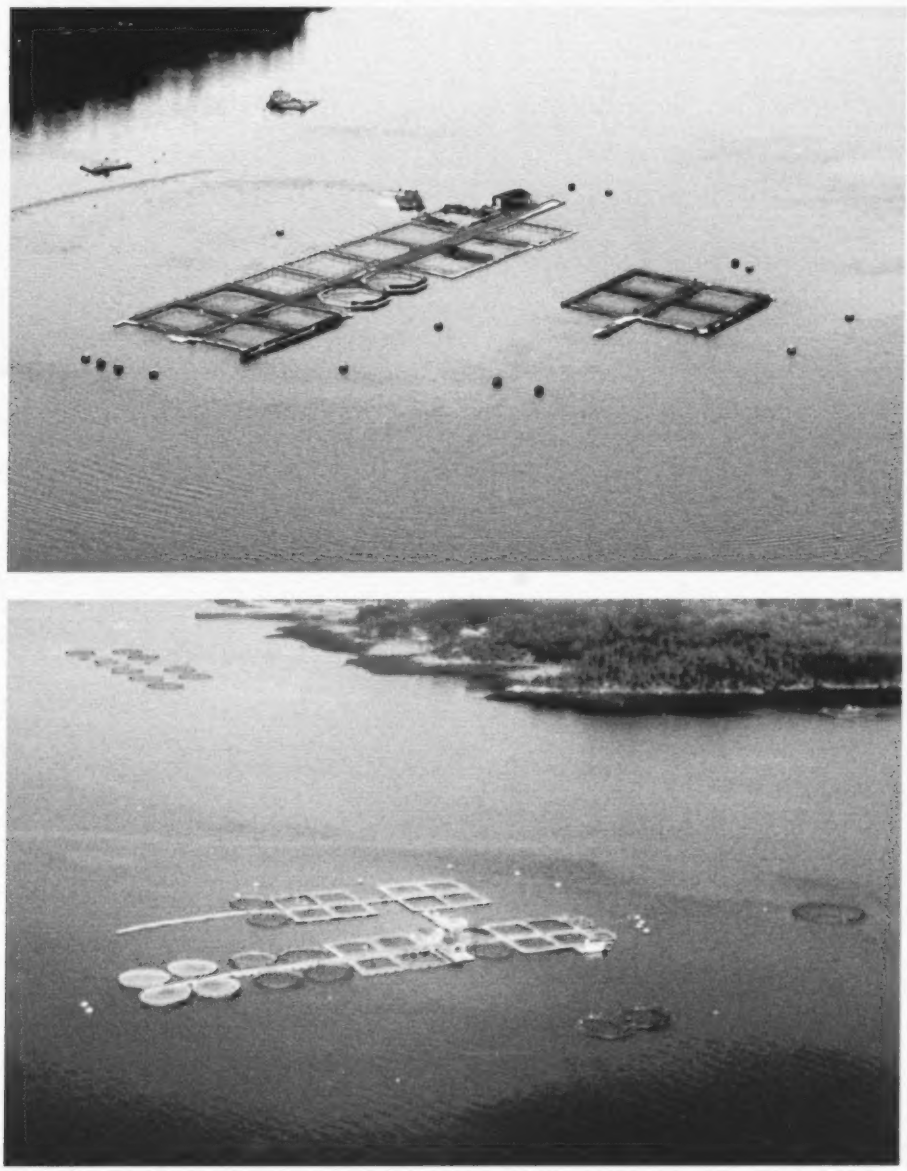


Fig. 17. Cage types used in southwestern New Brunswick. Various cage types being tested at the Atlantic Salmon Demonstration and Development Farm (in ABMA 2a): the top photo shows cages with octagonal wooden, square metal, and square plastic collars in 1992; the bottom photo shows cages with square metal and circular plastic collars in 1997. Photo credits: B.D. Chang (DFO, St. Andrews, NB).

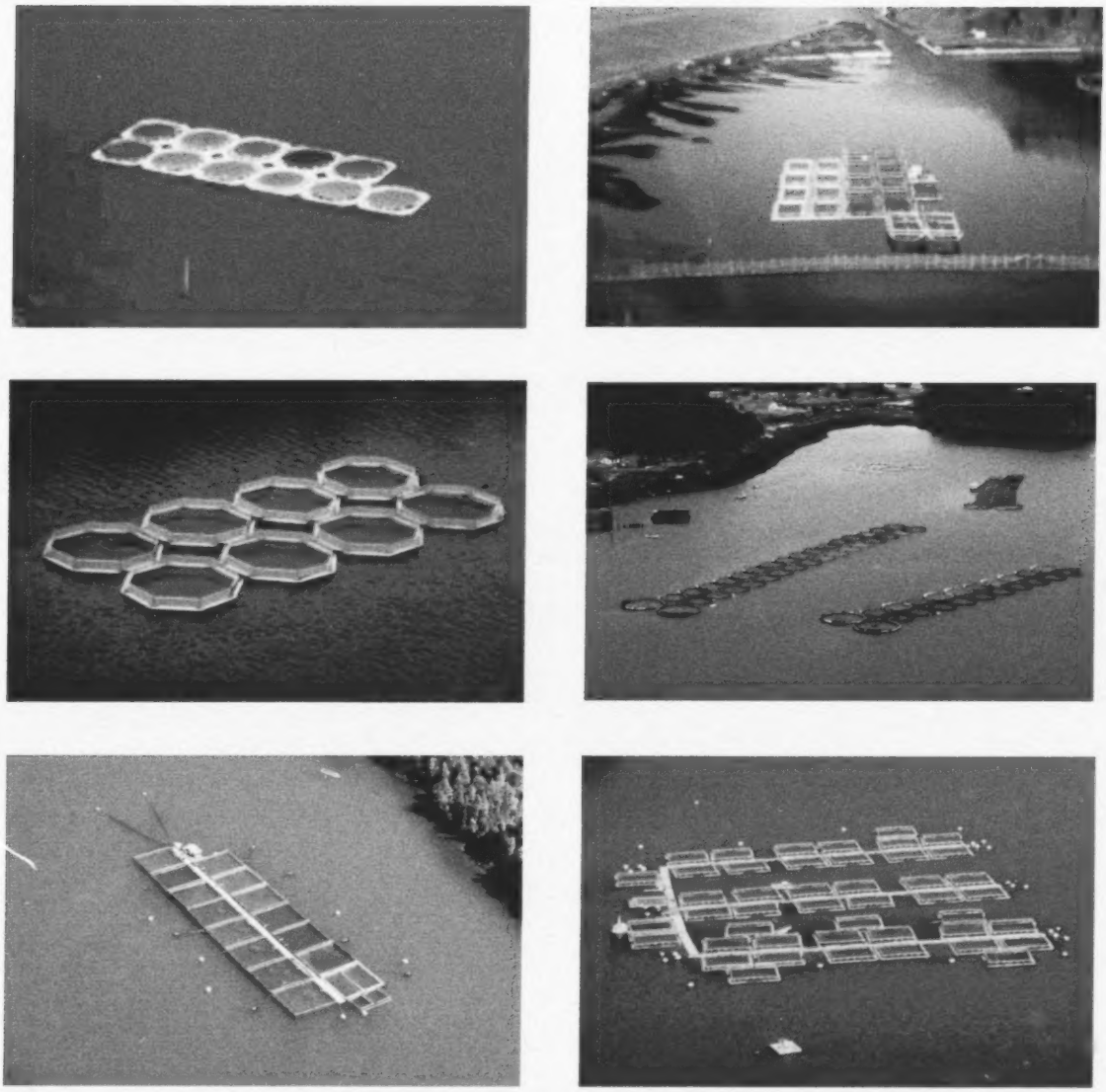


Fig. 17 (cont'd). Cage types used in southwestern New Brunswick. Top row, left: cages with wooden octagonal collars at the first salmon farm at Lords Cove, Deer Island, 1982. Top row, right: cages with wooden rectangular collars at the second salmon farm at Dark Harbour, Grand Manan Island, 1983. Second row: wooden "Malloch" cages (left, octagonal collars, 1987; right, octagonal and 12-sided collars, 1992). Bottom row, left: cages with square wooden collars, 1990. Bottom row, right: cages with square plastic collars, 1990. Photo credits: P.W.G. McMullon (1982-1987) and B.D. Chang (1990-1992) (DFO, St. Andrews, NB).

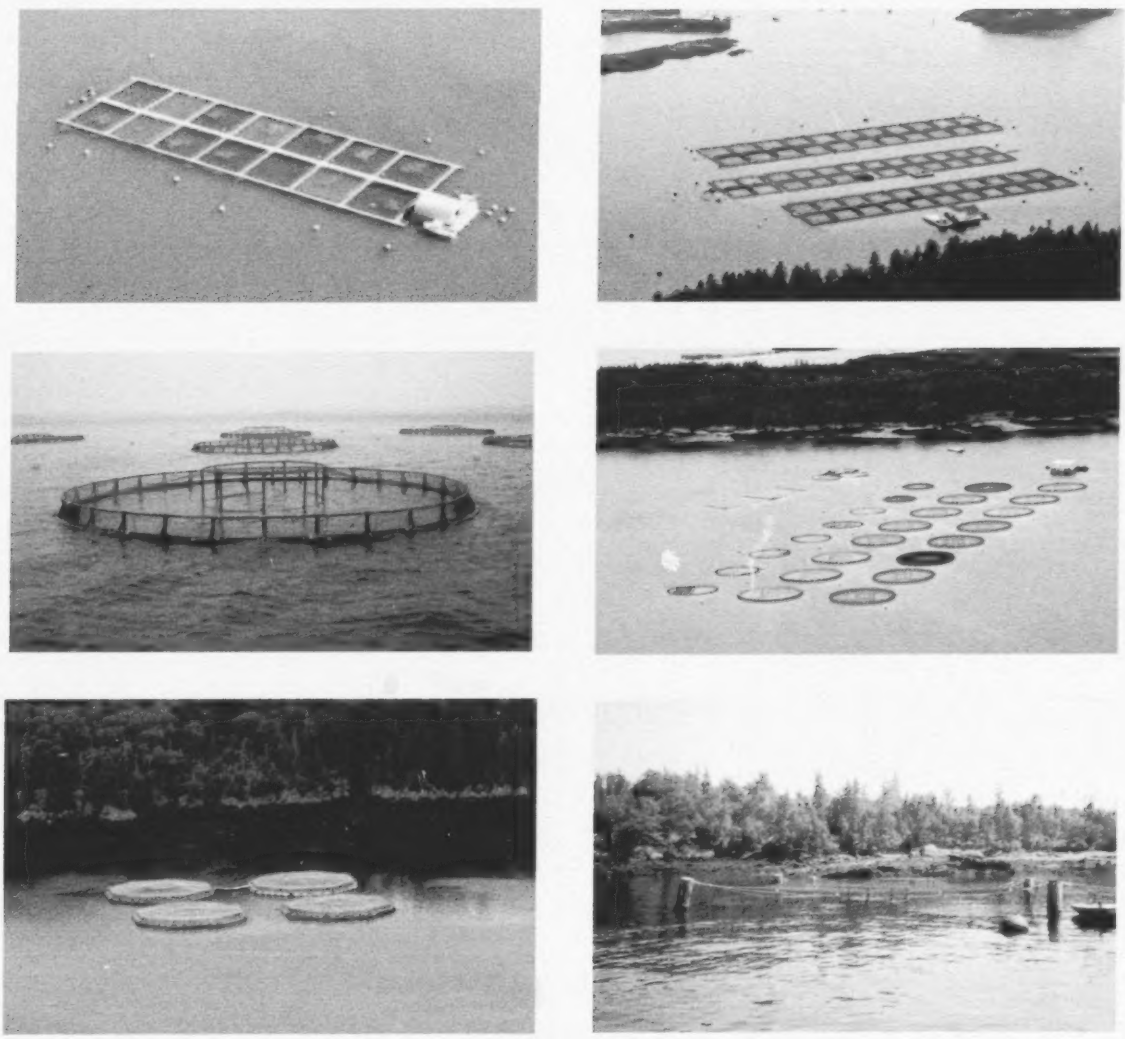


Fig. 17 (concluded). Cage types used in southwestern New Brunswick. Top row: cages with square metal collars (left, 1990; right, 1997). Second row: cages with circular plastic collars (left, 2006; right, an Integrated Multi-trophic Aquaculture site with salmon cages, mussel cages and kelp rafts, 2008). Bottom row, left: cages with octagonal steel collars, 2008. Bottom row, right: OceanSpar AquaSpar™ cages, 2001. Photo credits: B.D. Chang (1990-2006) and J.A. Cooper (2008) (DFO, St. Andrews, NB).

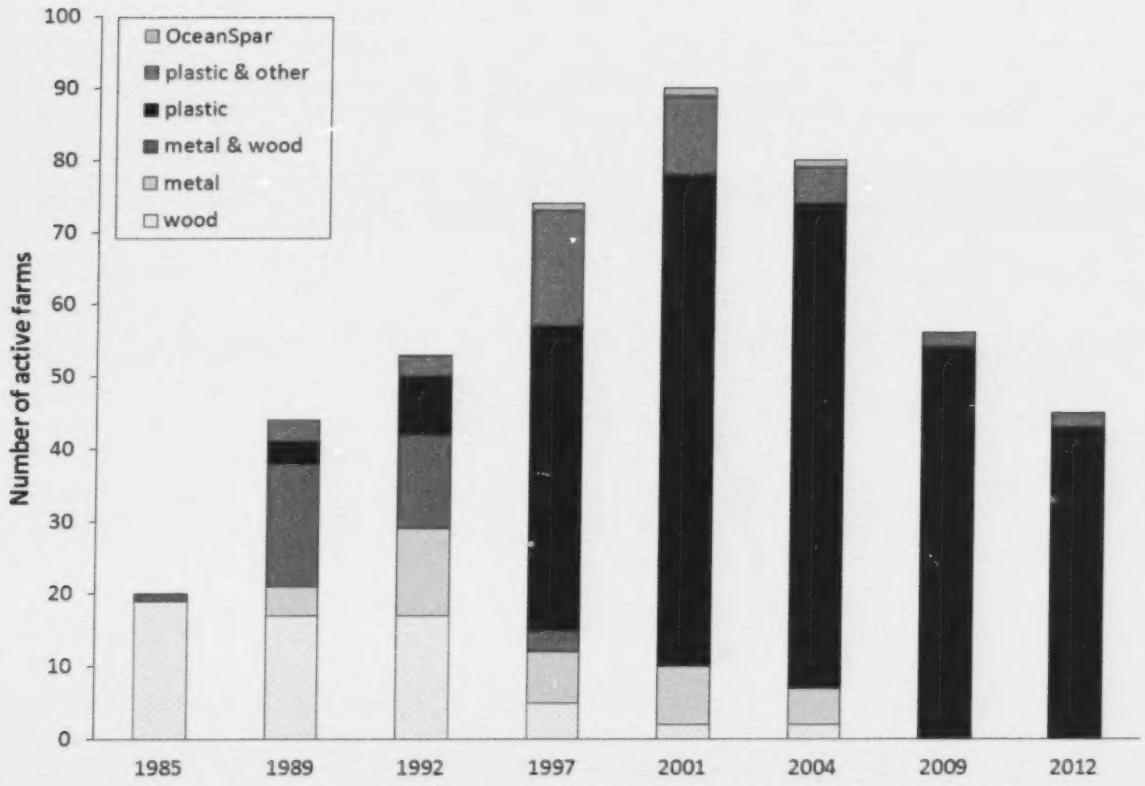


Fig. 18. Trends in cage types at active salmon farms in southwestern New Brunswick since 1985. Prior to 1985, all farms used cages with wooden collars. Data sources: FGA & WGA (1988); Anderson (2007); Google Earth (www.google.com/earth/index.html); GeoNB Map Viewer (geonb.snb.ca/geonb/); aerial photographs from 1989 provided by NBDELG (Fredericton, NB); aerial photographs taken in 1982-1990 by P.W.G. McMullon and in 1990-2001 by B.D. Chang (DFO, St. Andrews, NB); NBDAAF (St. George, NB).

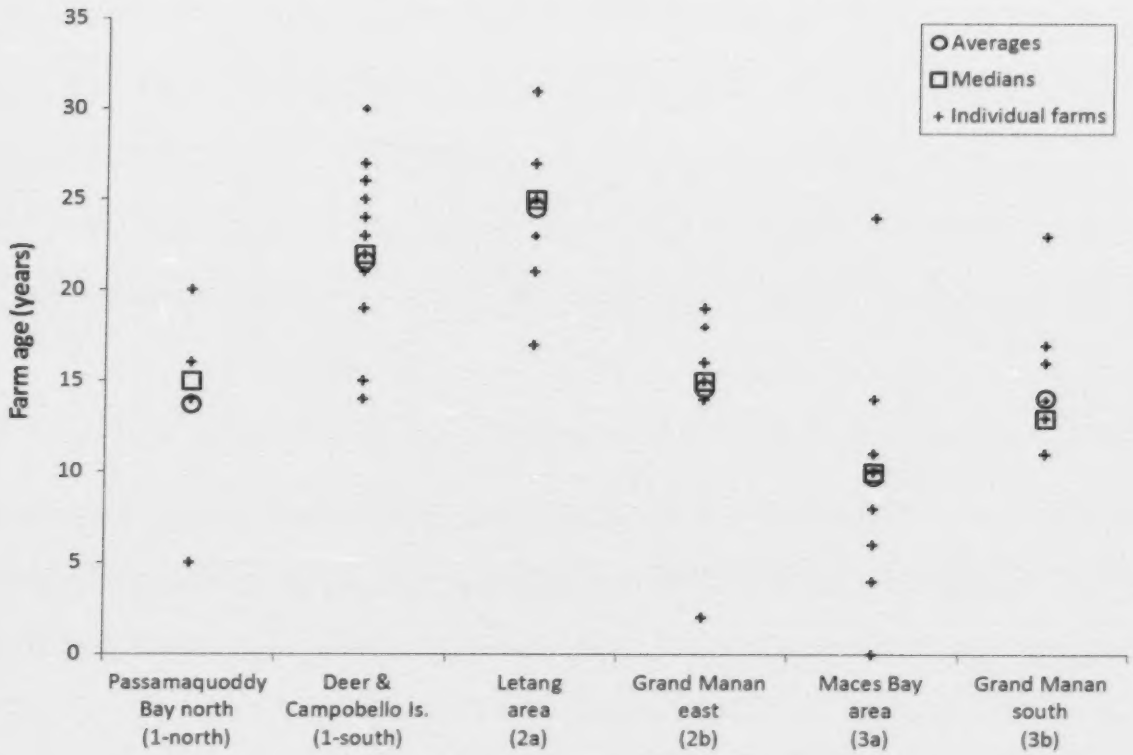


Fig. 19. Ages of salmon farms in each Aquaculture Bay Management Area, for farms active in 2010-2012. Farm age is the time in years between 2012 and the first year of operation (regardless of whether the farm was active during all of the intervening years). Data source: NBDAAF (St. George, NB).

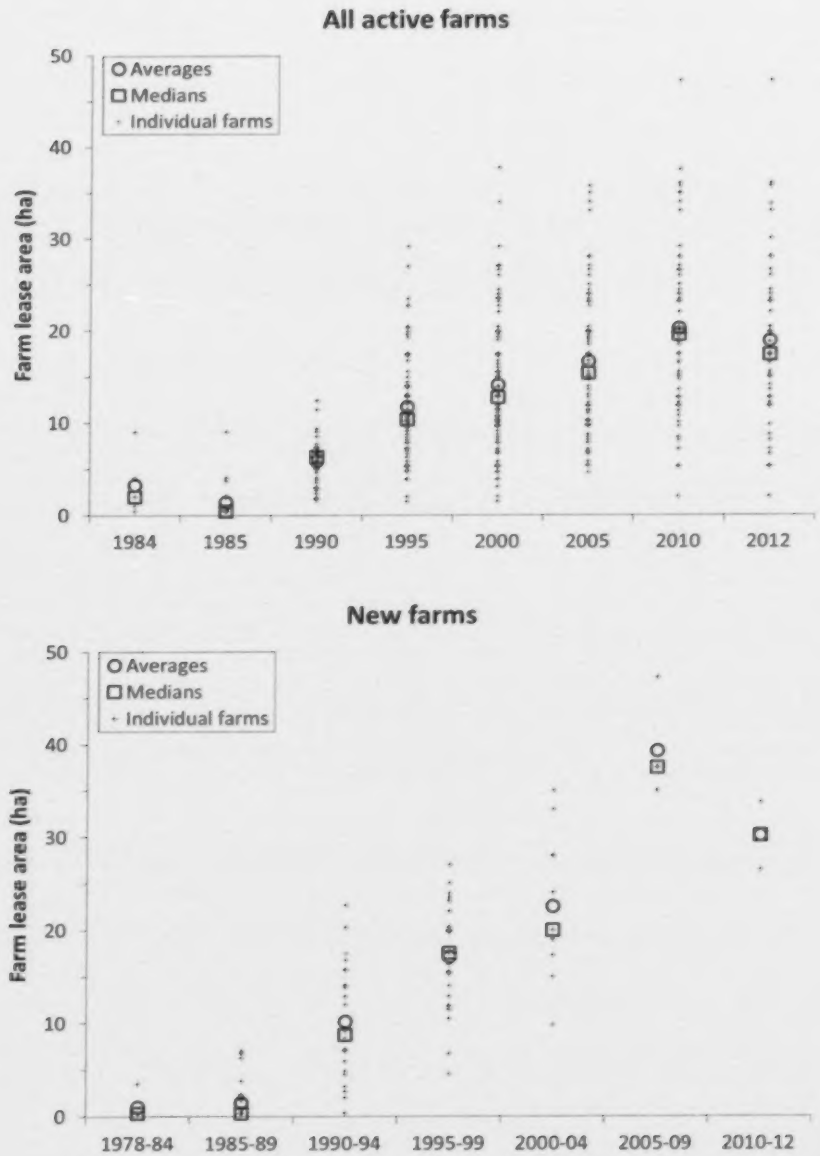


Fig. 20. Lease areas of salmon farms in southwestern New Brunswick, by year. Top: all active farms in each year indicated. Bottom: new farms starting within each time interval. Lease areas exclude foreshore areas above normal low tide. Data were not available for the farm operated at Dark Harbour, Grand Manan Island during 1980-2007. Data sources: NBDAAF (2014); NBDAAF (St. George, NB); New Brunswick Department of Natural Resources (Fredericton, NB).

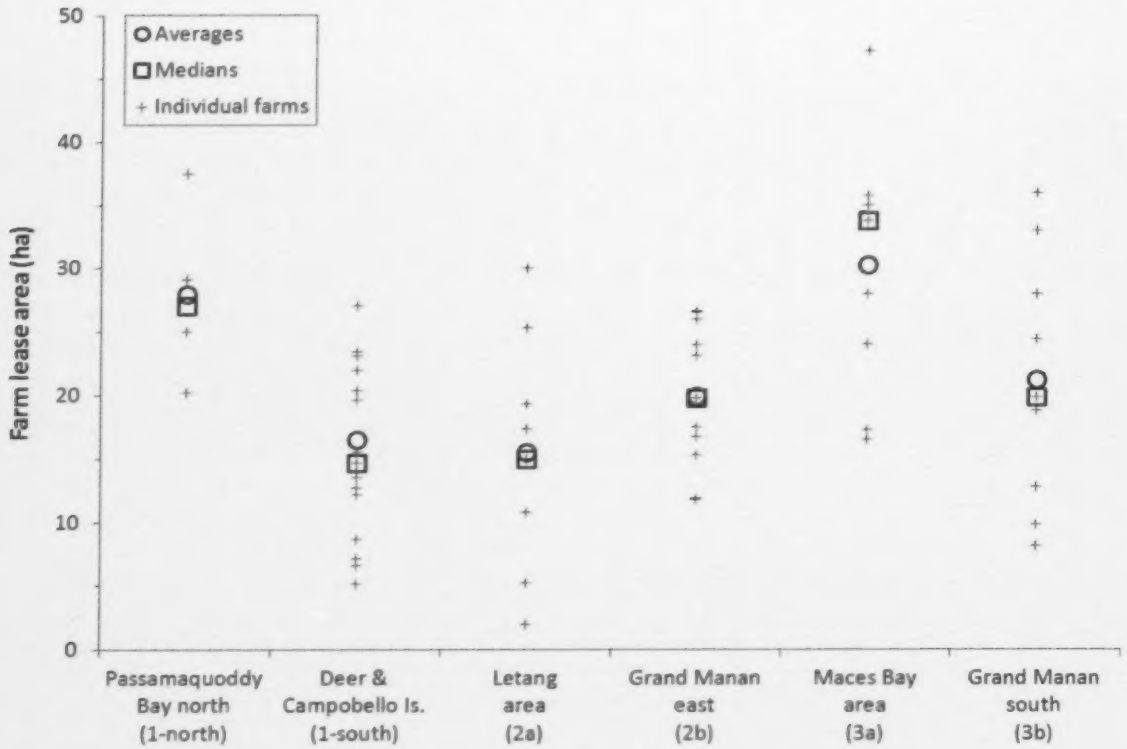


Fig. 21. Lease areas of salmon farms in each Aquaculture Bay Management Area, for farms active during 2010-2012. Lease areas exclude foreshore areas above normal low tide. Data sources: NBDAAF (2014); NBDAAF (St. George, NB).

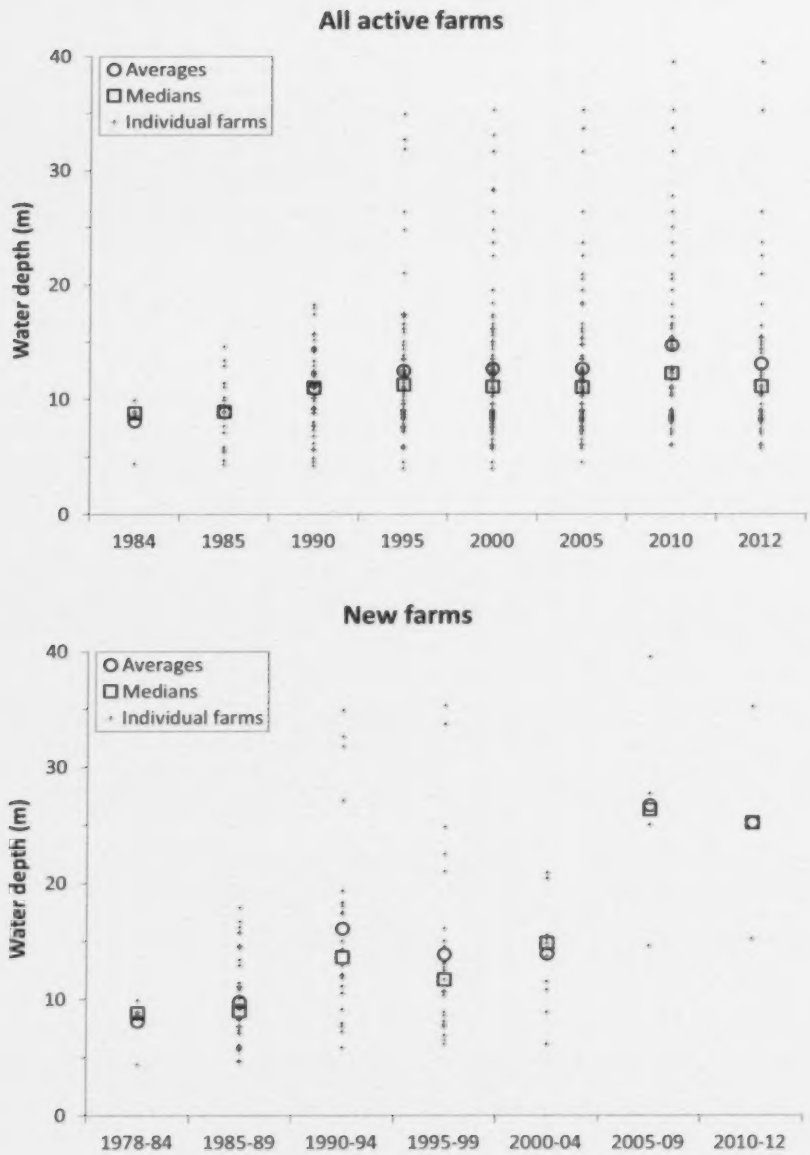


Fig. 22. Water depths at salmon farms in southwestern New Brunswick, by year. Top: all active farms in each year indicated. Bottom: new farms within each time interval. The water depth values for individual farms are the averages of depth soundings (relative to lowest normal tide) within each lease, excluding intertidal areas. Data were not available for the farm operated at Dark Harbour, Grand Manan Island during 1980-2007. Data sources: NBDAAF (2014); NBDAAF (St. George, NB); Canadi0an Hydrographic Service (Dartmouth, NS).

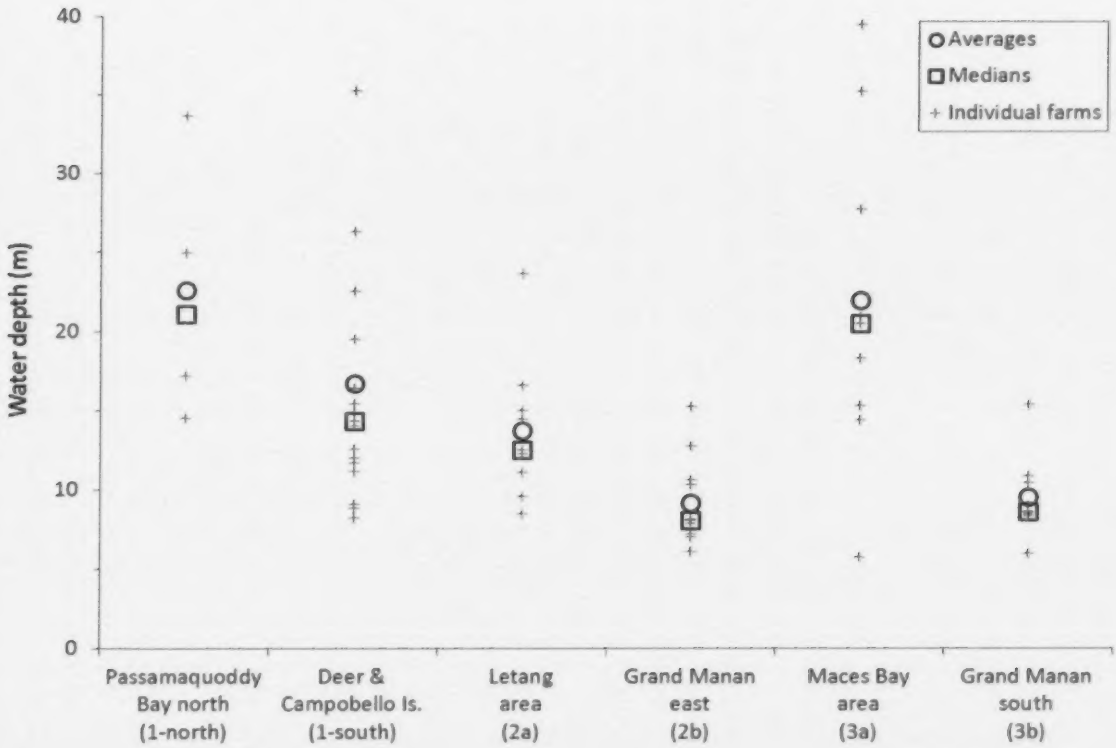


Fig. 23. Water depths at salmon farms in each Aquaculture Bay Management Area, for farms active during 2010-2012. The water depth values for individual farms are the averages of depth soundings (relative to lowest normal tide) within each lease, excluding intertidal areas. Data sources: NBDAAF (2014); Canadian Hydrographic Service (Dartmouth, NS).

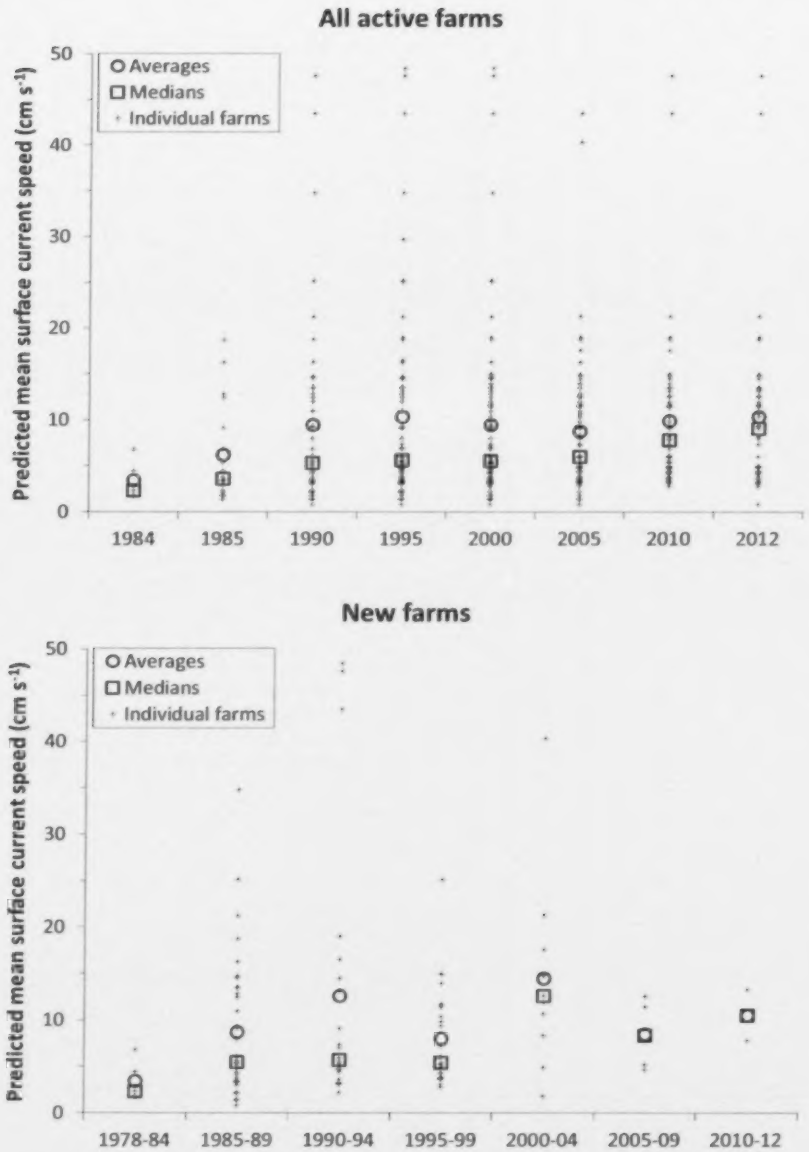


Fig. 24. Predicted mean surface current speeds at salmon farms in southwestern New Brunswick, by year. Top: all active farms in each year indicated. Bottom: new farms starting within each time interval. Data were not available for a farm operated at Dark Harbour, Grand Manan Island during 1980-2007. Current speeds were predicted using a circulation model (see text for information on methods).

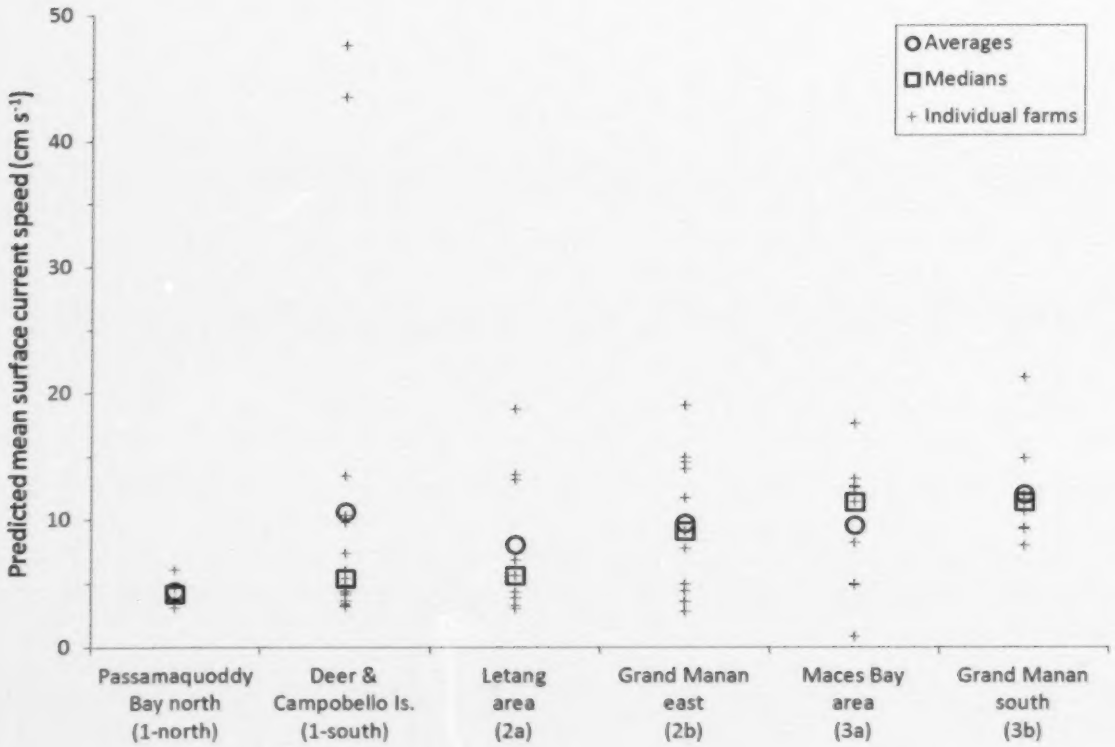


Fig. 25. Predicted mean surface current speeds at salmon farms in each Aquaculture Bay Management Area, for farms active during 2010-2012. Current speeds were predicted using a circulation model (see text for information on methods).

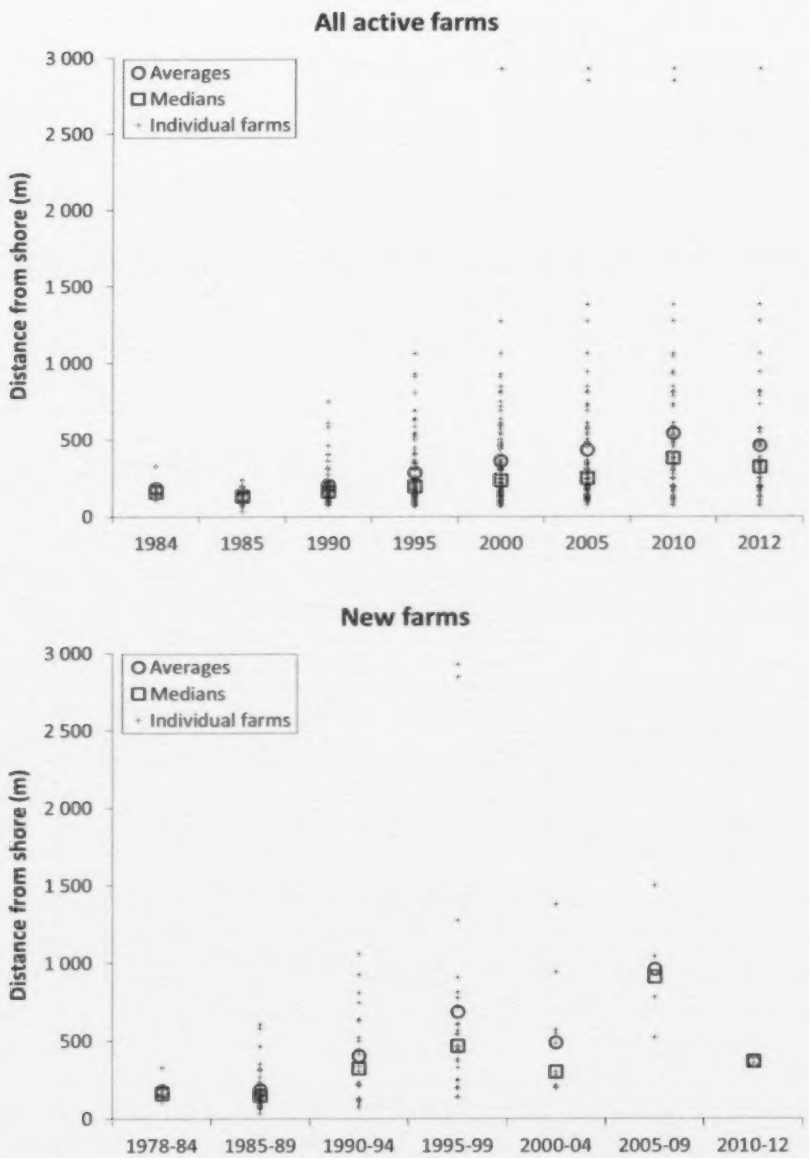


Fig. 26. Distances from the shore for salmon farms in southwestern New Brunswick, by year. Top: all active farms in each year indicated. Bottom: new farms starting within each time interval. The distance for each farm is the shortest path through water between the approximate farm centre and the coastline (the high water line, excluding islands <10 ha in area). Data sources: NBDAAF (2014); NBDAAF (St. George, NB).

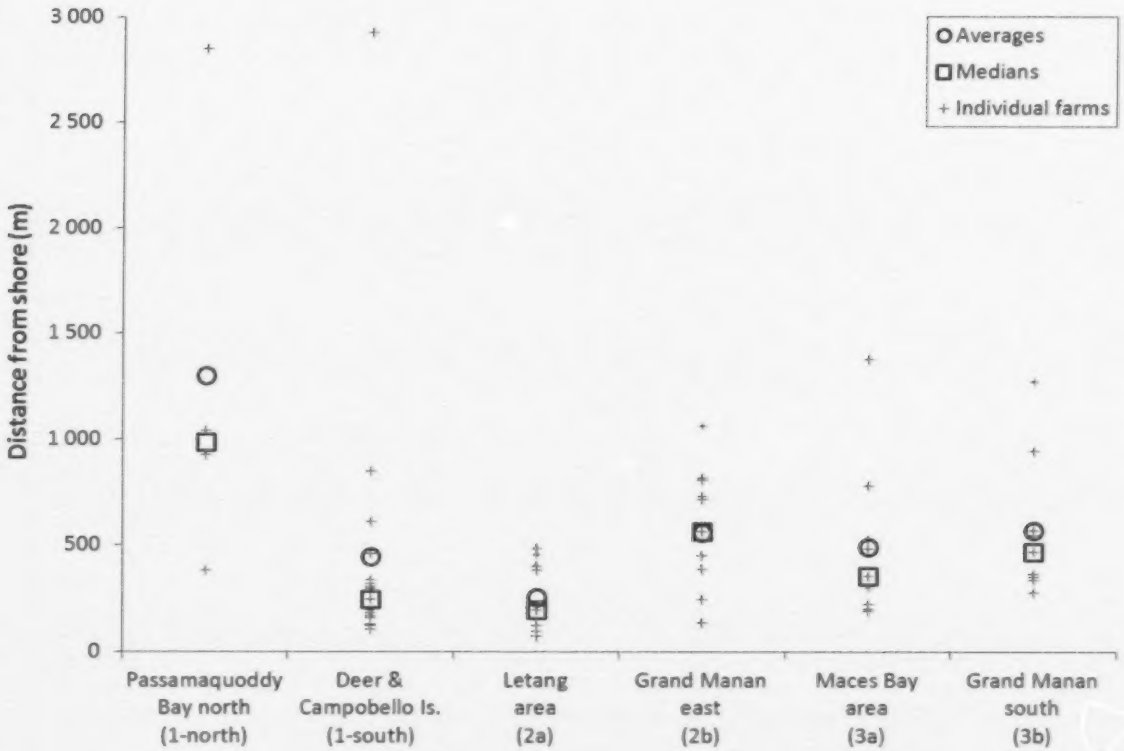


Fig. 27. Distances from the shore for salmon farms within each Aquaculture Bay Management Area, for farms active during 2010-2012. The distance for each farm is the shortest path through water between the approximate farm centre and the coastline (the high water line, excluding islands <10 ha in area). Data source: NBDAAF (2014).

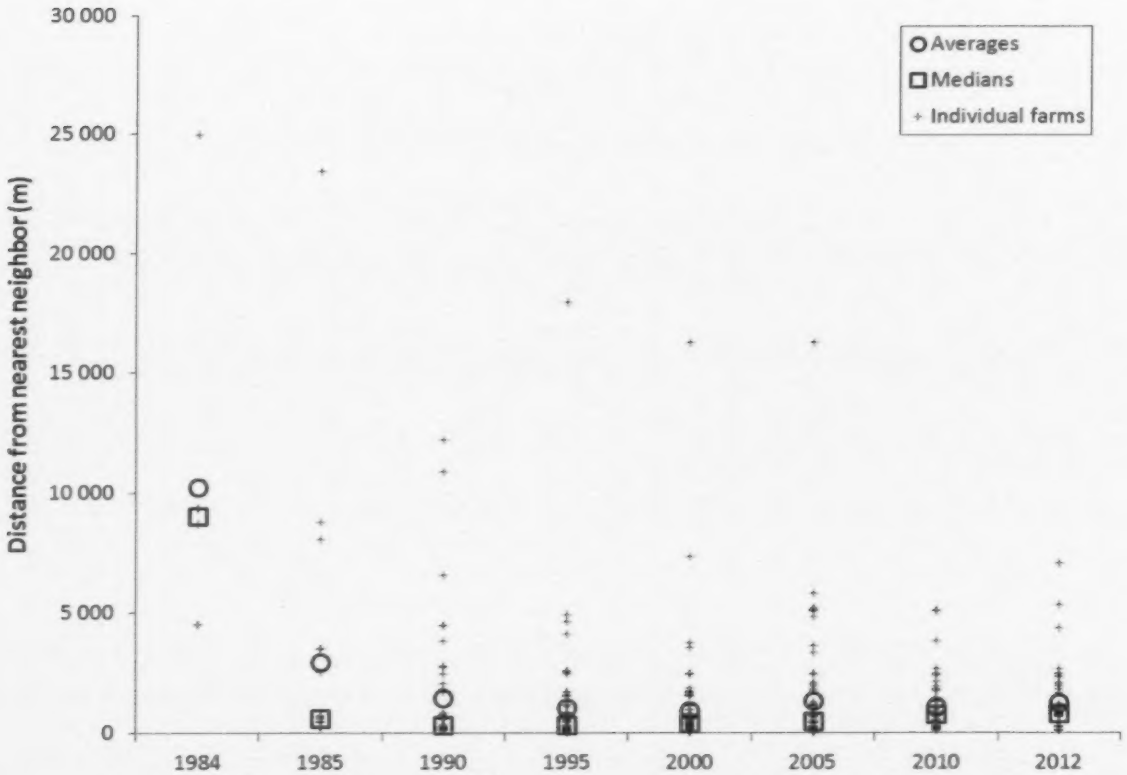


Fig. 28. Distances between nearest neighboring active salmon farms in southwestern New Brunswick, by year. The distances shown are the shortest paths through water (at high tide) between each lease boundary and the lease boundary of its nearest active neighbor. Data sources: NBDAAF (2014); NBDAAF (St. George, NB); New Brunswick Department of Natural Resources (Fredericton, NB).

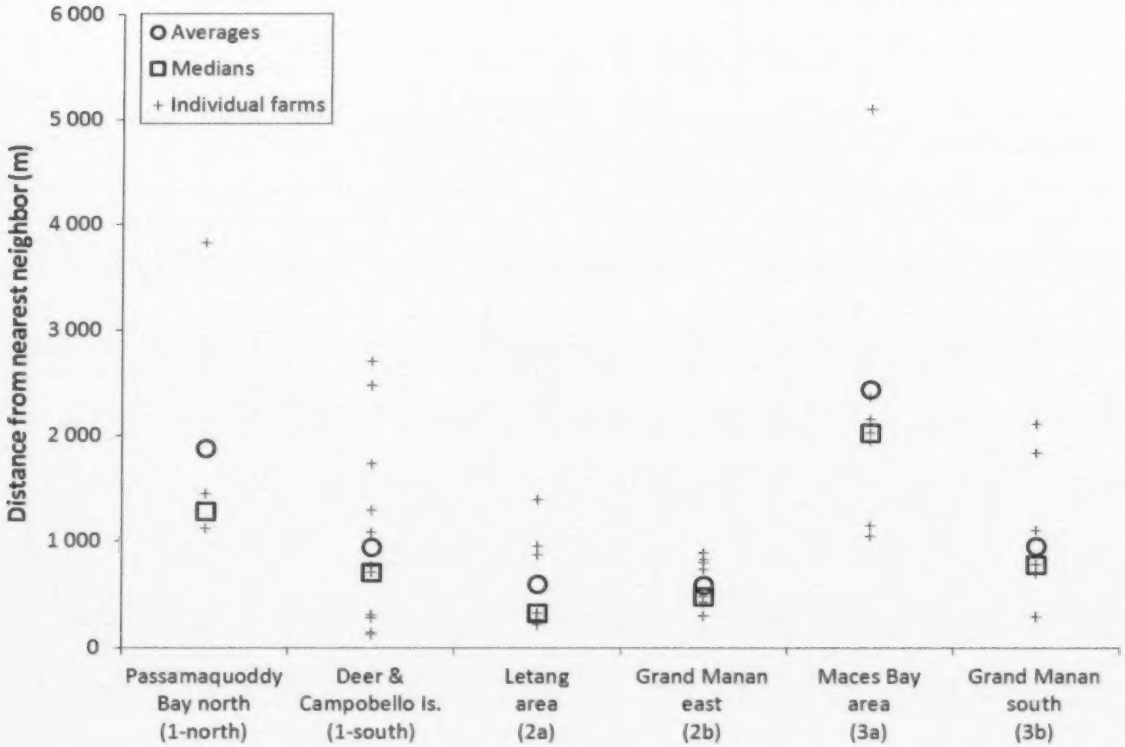


Fig. 29. Distances between nearest neighboring salmon farms in each Aquaculture Bay Management Area, for active farms during 2010-2012. The distances shown are the shortest paths through water (at high tide) between each lease boundary and the lease boundary of its nearest active neighbor. Data source: NBDAAF (2014).

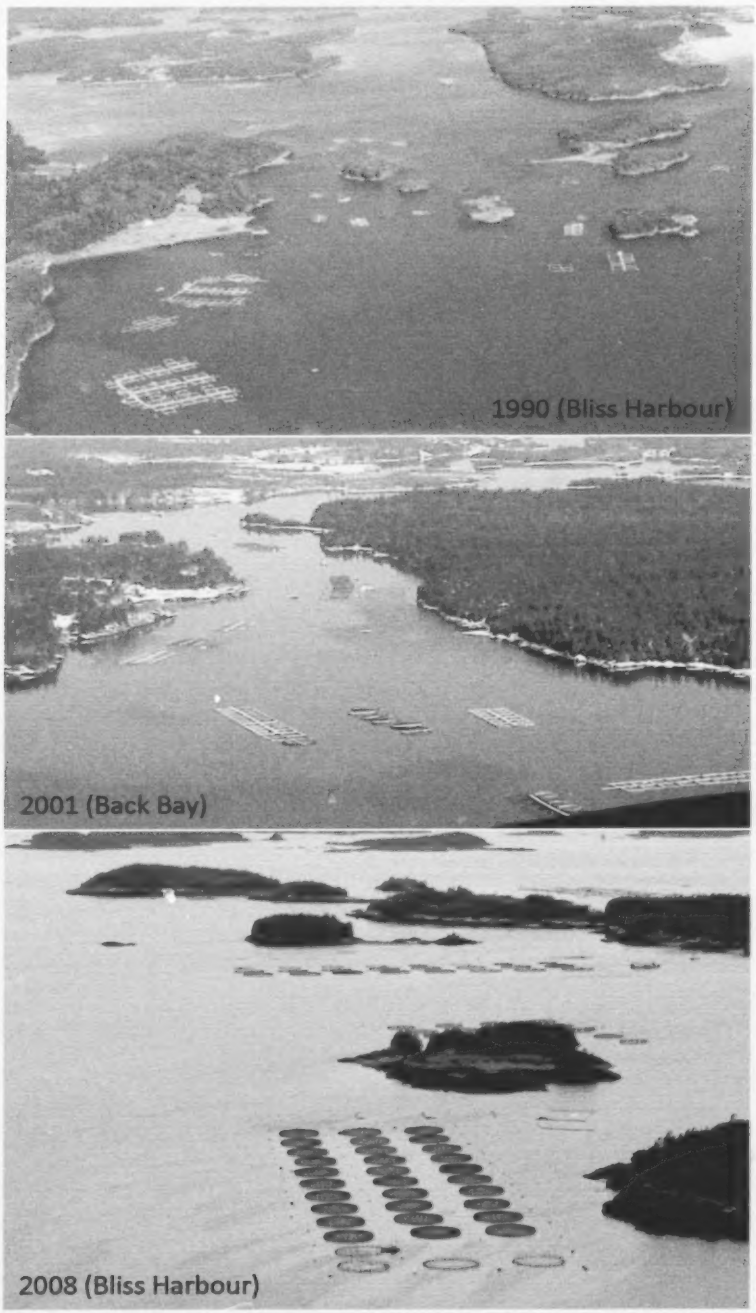


Fig. 30. Aerial photos showing the high density of salmon farms in the Letang area (ABMA 2a). Top: 1990 (Bliss Harbour). Middle: 2001 (Back Bay). Bottom: 2008 (Bliss Harbour). Photo credits: B.D. Chang (top and middle) and J.A. Cooper (bottom) (DFO, St. Andrews, NB).

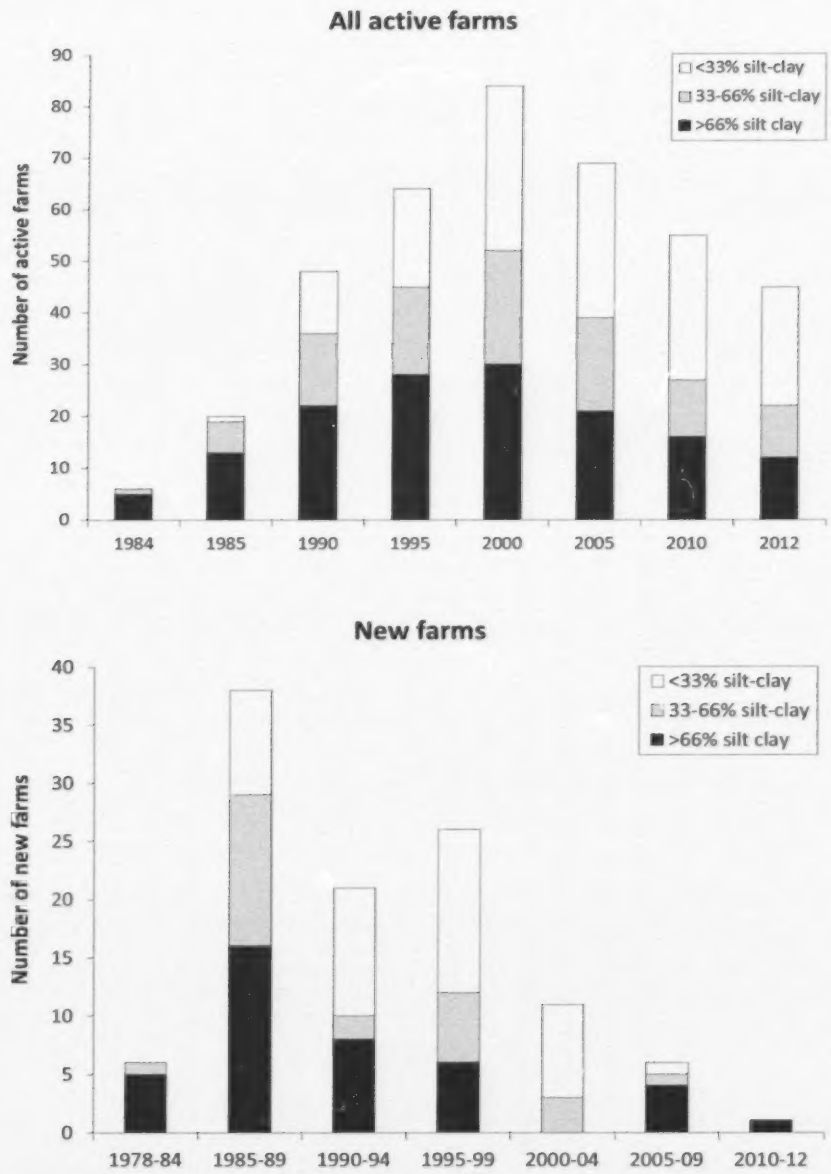


Fig. 31. Seafloor sediment types at salmon farms in southwestern New Brunswick, by year. Top: all active farms in each year indicated. Bottom: new farms starting within each time interval. Farms were classed according to the % silt-clay in the seafloor sediment. Data source: NBDAAF (St. George, NB).

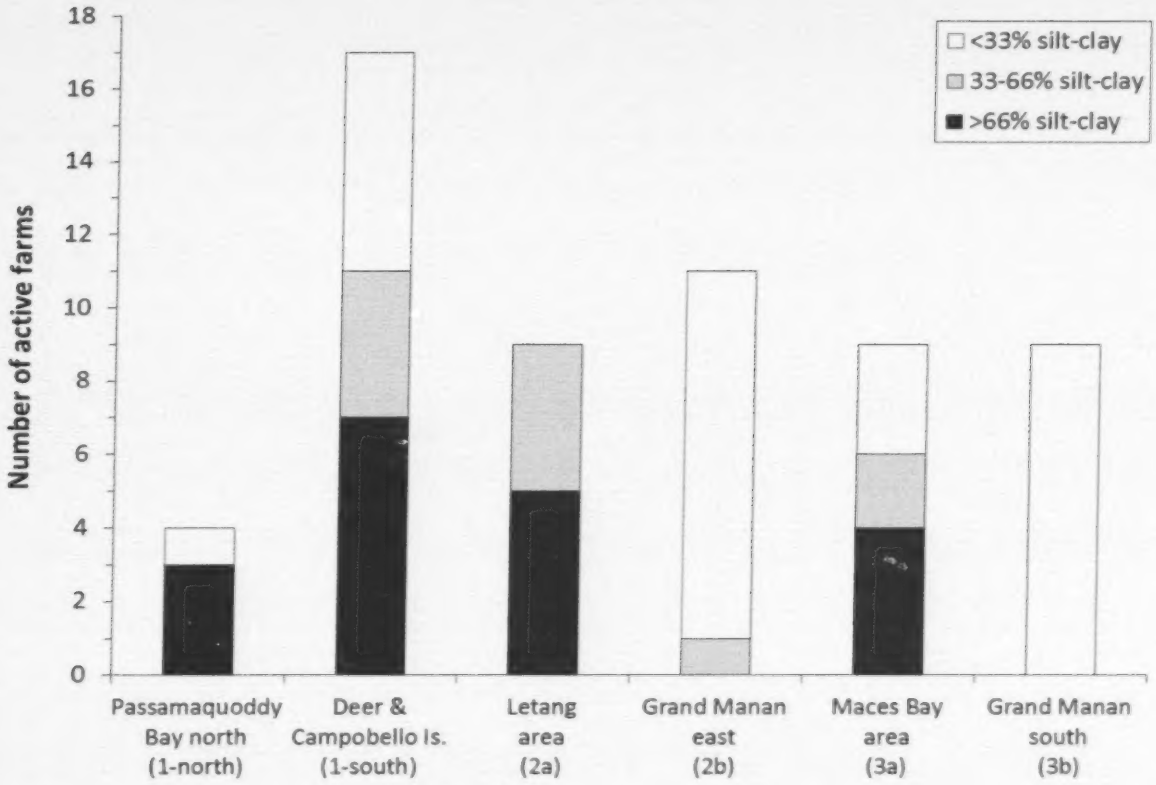


Fig. 32. Seafloor sediment types at salmon farms in each Aquaculture Bay Management Area, for farms active during 2010-2012. Farms were classed according to the % silt-clay in the seafloor sediment. Data source: NBDAAF (St. George, NB).

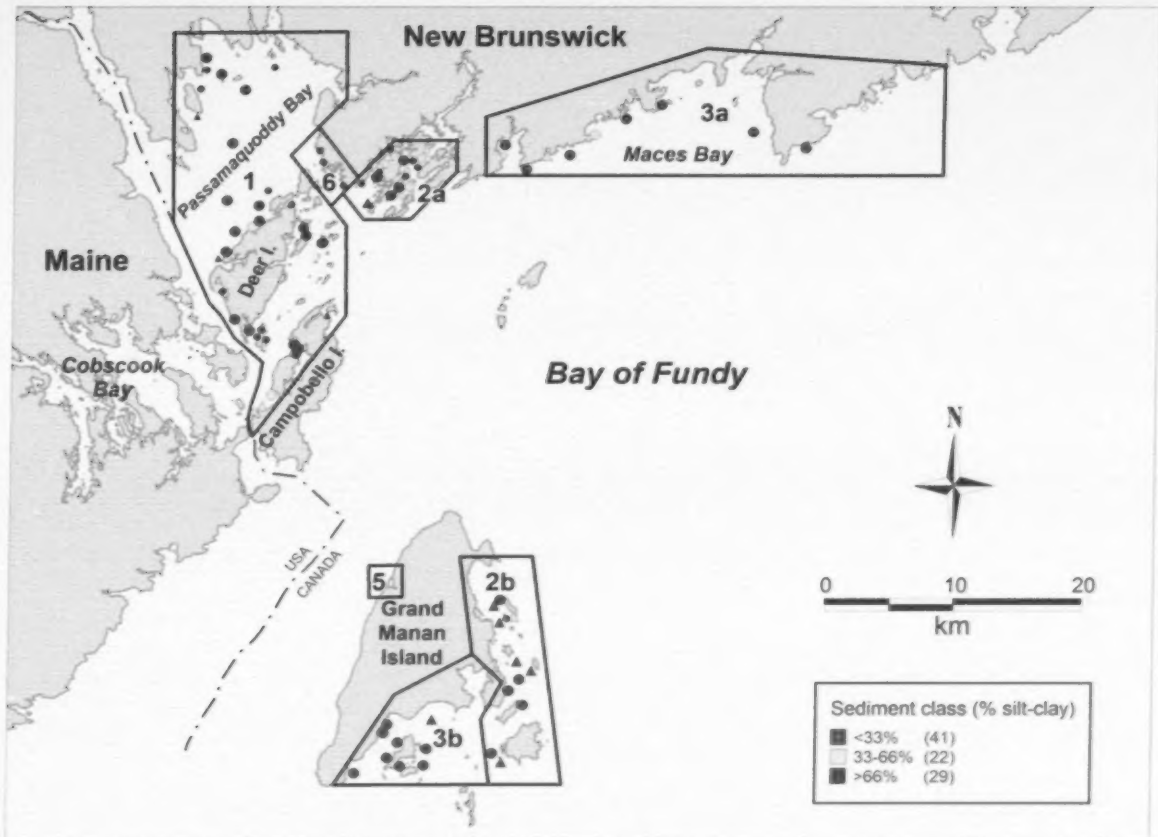


Fig. 33. Seafloor sediment types at finfish farms in southwestern New Brunswick, classed according to % silt-clay. Circles indicate 77 farms for which quantitative % silt-clay data were available; triangles indicate 15 farms for which the sediment class was estimated from qualitative sediment descriptions. Larger symbols represent 59 salmon farms that were active during 2010-2012; smaller symbols represent 33 other farms (29 inactive and 4 growing non-salmonids). The numbers in parentheses in the legend indicate the number of farm leases (of the total 92 finfish leases in 2012) in each sediment class. Black outlines indicate Aquaculture Bay Management Areas. Data source: NBDAAF (St. George, NB).

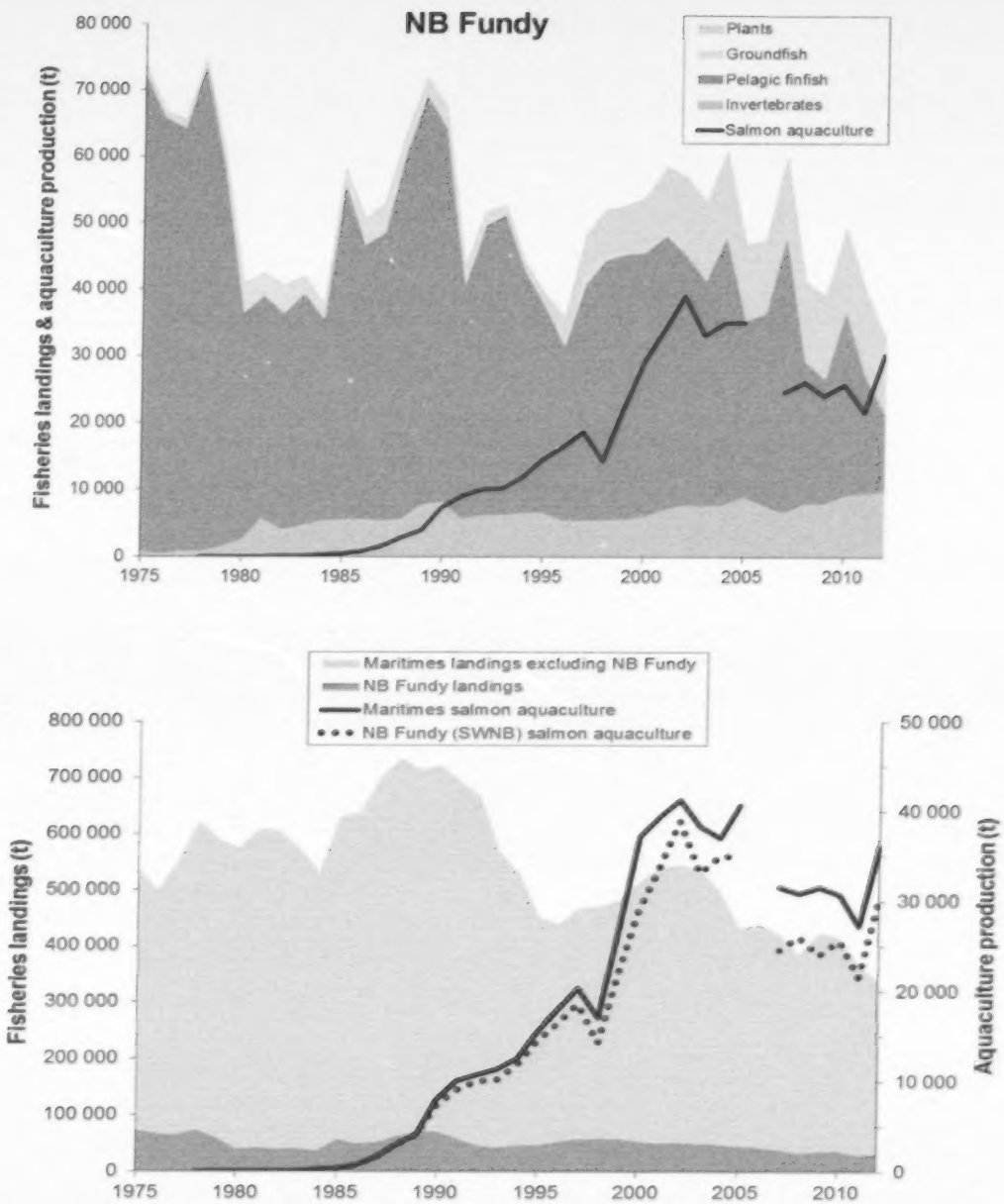


Fig. 34. Commercial fisheries landings in the New Brunswick portion of the Bay of Fundy (NB Fundy), 1975-2012. Top: NB Fundy fisheries landings (by major groups). Bottom: NB Fundy landings (all species combined) in relation to total Maritimes landings. Also shown is salmon aquaculture production per year (data not available for 2006). Data sources for fisheries landings: DFO (2014b); DFO Policy & Economics Branch (Dartmouth, NS).

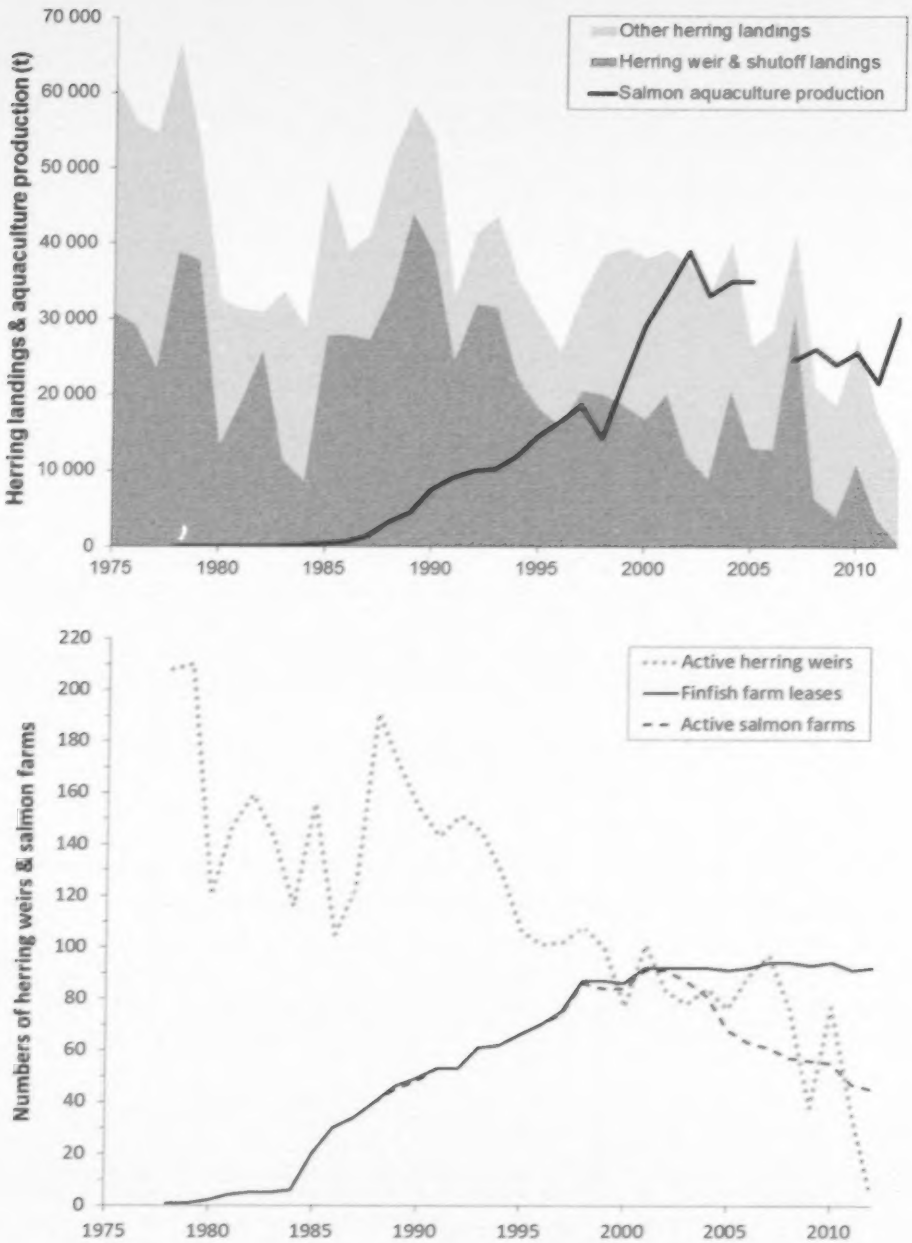


Fig. 35. The herring fishery and salmon aquaculture in the New Brunswick portion of the Bay of Fundy, 1975-2012. Top: Herring landings and aquaculture production quantities; "other" herring landings were mostly purse seine; salmon production data are from Fig. 2. Bottom: numbers of active herring weirs, finfish farm leases, and active salmon farms, 1978-2012; finfish farm data are from Fig. 8. Data sources for the herring fishery: Power et al. (2013); DFO (2013a, 2014b).

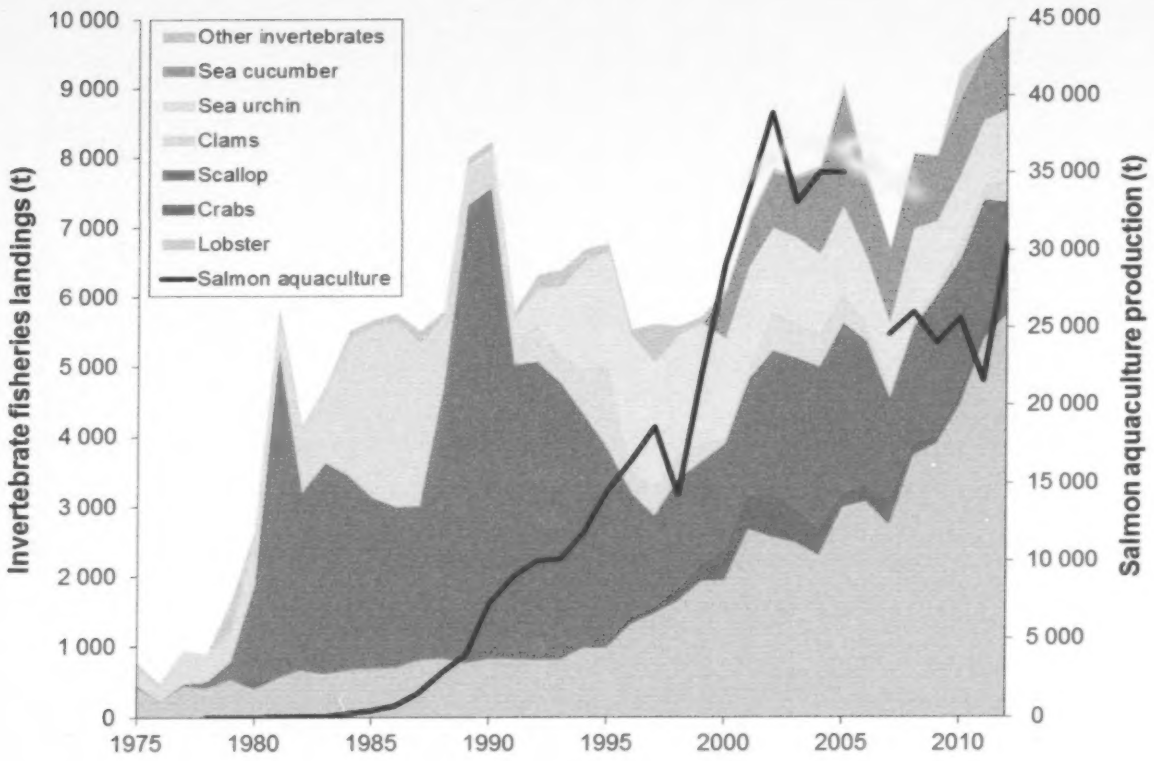


Fig. 36. Invertebrate (shellfish) fisheries landings in the New Brunswick portion of the Bay of Fundy, 1975-2012. Also shown are salmon aquaculture production quantities per year for southwestern New Brunswick (from Fig. 2). Data sources for fisheries landings: DFO (2014b); DFO Policy & Economics Branch (Dartmouth, NS).

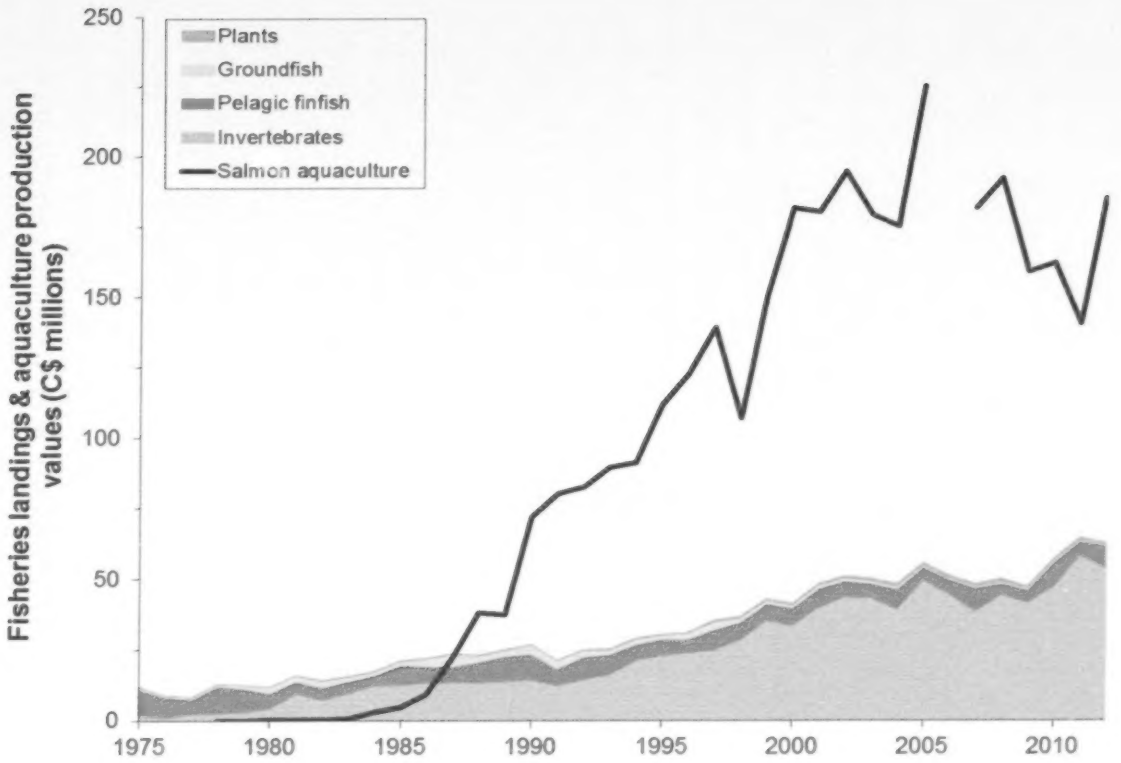


Fig. 37. Value of commercial fisheries landings (by major groups) in the New Brunswick portion of the Bay of Fundy, 1975-2012. Also shown is the value of salmon aquaculture production for southwestern New Brunswick (from Fig. 2). Values are in Canadian dollars (C$). Data sources for fisheries landings: DFO (2014b); DFO Policy & Economics Branch (Dartmouth, NS).

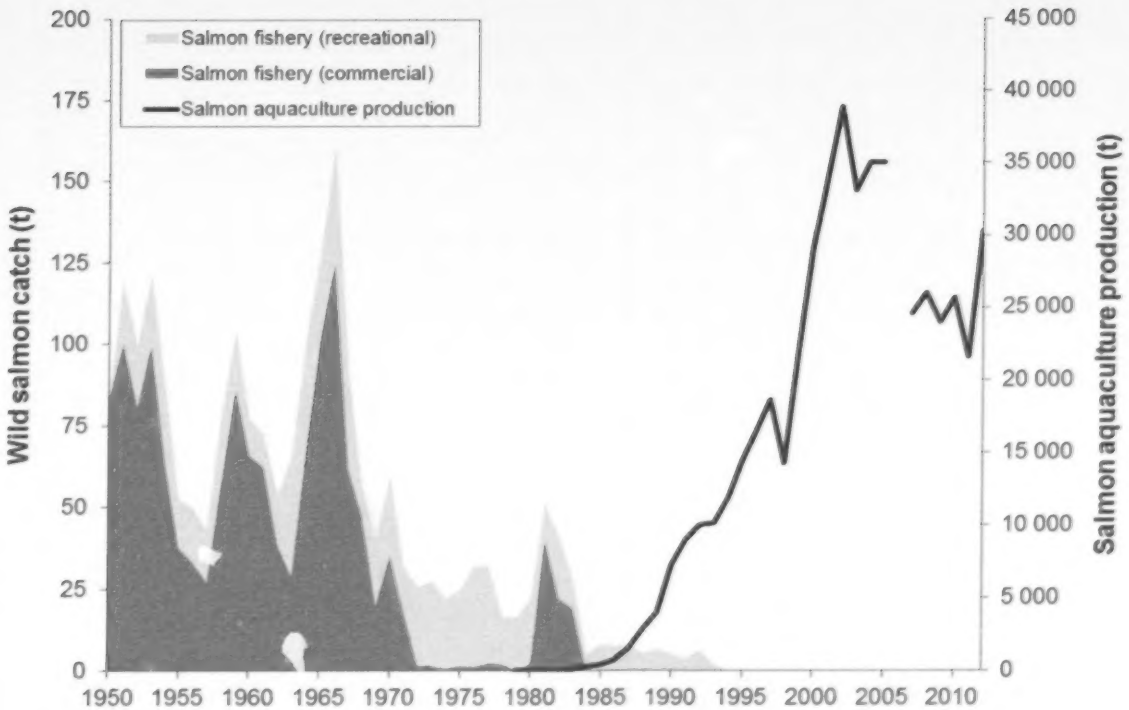


Fig. 38. Wild salmon catches and salmon aquaculture production in the New Brunswick portion of the Bay of Fundy, 1950-2012. The commercial fishery for wild salmon in the Bay of Fundy was closed in 1983 and the recreational fishery was closed in 1997. Data were not available for the recreational fishery catch in 1950. Salmon aquaculture production data are from Fig. 2. Data sources for the wild salmon fishery: May & Lear (1971); Cutting (1984); Smith (1981); Swetnam & O'Neil (1984); O'Neil et al. (1985, 1986, 1987, 1989, 1991); DFO (2013b).